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Muskeg River Watershed Management Framework Second Annual Report

October 2011

Government of Alberta

Muskeg River Watershed Management Framework – Second Annual Report (October, 2011)

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EXECUTIVE SUMMARY

In 2008, Alberta Environment adopted a management framework for the Muskeg River watershed. The management framework defines criteria for evaluation of water quantity and water quality in the Muskeg River watershed. Observed conditions are compared against scientifically established limits that have been developed specifically for the Muskeg River Watershed. These limits are based on data collected within the watershed, as well as more broad information on streamflow, water quality and requirements of the aquatic ecosystem.

One of the key recommendations of the management framework was the development of an integrated monitoring program for the Muskeg River watershed to coordinate off-lease monitoring activities that are currently conducted by individual companies and Alberta Environment.

The main purpose of the integrated monitoring plan is to support the recommendations of the management framework which specify targets and limits for water quality and water quantity. This report presents the findings of the integrated monitoring program for 2009–2010.

Water Quantity – Key Findings

- Water quantity was assessed using the water levels at Kearl Lake, flow rates at the Muskeg River near Fort Mackay (site M2), and water diversions from the Muskeg River basin. No management actions were recommended for water quantity.
- For most of 2009 and 2010, the water levels at Kearl Lake remained between the minimum objective (331.71 m) and target level (331.94 m), as established under the management framework. The average water level of 331.89 m in 2009 and 331.88 m in 2010 indicated the Kearl Lake water levels were within the range of normal fluctuation.
- Flow rates for the Muskeg River remained well within the green condition for most of 2009 and 2010. A few instances of red condition were recorded in the early spring of 2009 and 2010, in December of 2009 and in the summer of 2010. These were the result of a slight delay of spring runoff and relatively low precipitation in the lower Athabasca Region in June and July of 2010.
- In 2010, four oil sands mining projects were authorized under the *Water Act* to withdraw surface runoff and groundwater from the Muskeg River basin. These projects were not authorized to withdraw water directly from the Muskeg River but do capture surface water that contacts exposed oilsands or enters the mine processing area. Each project was required to submit data to Alberta Environment regarding water withdrawals and returns, and this water use data was summarized on a monthly basis. No water withdrawals exceeded the licence allocation volumes.

Water Quality – Key Findings

Water quality testing for 2009–2010 was conducted for a range of parameters, including metals, hydrocarbon-related organic components, general chemistry and nutrients. These parameters were measured against a range of criteria specified in the Management Framework to assess whether water quality targets and limits are exceeded.

- Aside from a few exceptions, the overall findings of the water quality testing for 2009–2010 were within the targets and limits of the Muskeg River Management Framework (MRMF). Several metals exceeded the MRMF targets but they appeared to have natural sources, which indicated a need to revise the targets. A red management condition was triggered by an exceedance of the peak total aluminum limit, indicating a need to evaluate how industry activities are contributing to these elevated concentrations. This issue was first identified by operators in relation to difficulties they experienced in attenuating suspended solids concentrations during site dewatering. Management actions have now been implemented by operators in the form of releases to wetlands rather than direct releases into the Muskeg River. The effectiveness of these management actions in relation to the MRMF and total aluminum loading will be assessed during the 2011 monitoring year.
- The peak total mercury concentrations observed in the Muskeg River at M2 were well below the draft provincial acute guideline. The mean total mercury concentrations were well below the provincial chronic guideline and were less than the average mercury concentrations in the lower Athabasca River. Neither of the tributaries are significant sources of mercury. No longitudinal trends were found.
- Heavy hydrocarbons were generally detected throughout the watershed. These detections occurred primarily in winter when groundwater seepage was the major contributor to river flows. The fact that detections occurred throughout the basin suggested that the hydrocarbon load was associated with natural sources; however it is difficult to separate the natural signals from the anthropogenic ones in the context of the distinct hydrogeologic gradient of the Muskeg River basin.
- As with heavy hydrocarbons, naphthenic acid concentrations were also inversely related to river flow, which indicated a seepage-related source. The absence of distinct steps in naphthenic acid concentrations between sites suggested minimal influence from process-related seepage.

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1.0 INTRODUCTION

The Muskeg River Water Management Framework for water quantity and quality was completed and released in June 2008 and is accessible through the following web link: http://www.environment.alberta.ca/01245.html. One of its recommendations was the development of an integrated monitoring plan for the Muskeg River watershed, with cooperation from industry stakeholders. The plan was to coordinate off-lease monitoring activities that would otherwise be done by individual companies. This coordination provided an effective and efficient means to compare the status of water quality at any site, increased sampling to a monthly basis, and resulted in a vast improvement in terms of scientific rigor. In this way, all water samples would be collected within the same time periods subjected to the same laboratory analytical protocols.

The management framework defined criteria for evaluating water quantity and water quality. The observed conditions are to be compared against scientifically established limits that have been developed specifically for the Muskeg River watershed. These limits are based on data collected within the watershed, as well as additional information on streamflow, water quality and requirements of the aquatic ecosystem.

The integrated monitoring program satisfies some of the monitoring requirements under existing *Environmental Protection and Enhancement Act* (EPEA) approvals, specifically monitoring of the receiving water body, typically both upstream and downstream of a project site. The main purpose of the integrated monitoring program is to support the recommendations of the Muskeg River Water Management Framework that specify targets and limits for water quality and water quantity. This program complements and builds on pre-existing monitoring programs, but does not replace specific monitoring programs such as the fish toxicity, benthic macroinvertebrate, and sediment monitoring programs presently being conducted. It also does not replace industry water quality and quantity monitoring on their Mineable Surface Leases or for their water releases – i.e., dewatering releases.

1.1 PURPOSE OF THE REPORT

This annual monitoring report is intended to meet the management framework requirement for reporting and communication of monitoring results conducted through the integrated monitoring program. The report provides a performance assessment of management actions that were implemented consistent with the triggers provided in the MRMF.

1.2 SCOPE OF THE REPORT

This report covers the period beginning from March 2009 to the most recent available and validated data of 2011. It analyses surface water quality and quantity data derived from the integrated monitoring program for the Muskeg River. The water quality parameters included in this report are found in Appendix 1. The list includes general chemistry and nutrient parameters, metals and organic constituents including hydrocarbons and organic acids. Surface water quantity assessment includes water levels in Kearl Lake, flow rates of the Muskeg River at site M2 and water diversions in the watershed.

1.3 Monitoring Sites

Surface water quality and quantity assessment involves compiling and summarizing monitored parameters from seven monitoring sites along the Muskeg River and its tributaries, and comparing these against established water quality triggers and limits. The two major tributary monitoring sites are Jackpine and Muskeg Creeks.

Table 1 and figure 1 show the location of the five monitoring sites along the mainstem:

- one site that until recently was relatively unaffected by surface mining activities,
- three sites located between Stanley, Muskeg and Jackpine Creeks, and
- one site at the Water Survey of Canada hydrometric gauging station, downstream of the Canterra haul road. The latter site is preferred to a site at the mouth of the Muskeg River as it has been monitored extensively over a relatively long period, is located upstream of the Athabasca River escarpment and is located directly downstream of all of the major surface mining activity in the basin.

Table 1. Monitoring sites in the Muskeg River basin that are part of the management framework

Monitoring Sites	Site #	Frequency
Muskeg River		
Muskeg River at WSC gauge site (AB07DA0610)	M2	monthly
Muskeg River upstream of Jackpine Creek (AB07DA0595)	M3	monthly
Muskeg River upstream of Stanley Creek (AB07DA0480)	M3	Monthly
Muskeg River upstream of Stanley Creek (AB07DA0475)	M4.5	monthly
Muskeg River 11 km upstream of Stanley Creek (AB07DA0420)	M6	monthly
Tributaries		
Jackpine Creek (mouth; AB07DA0600)	T3.1	monthly
Muskeg Creek (mouth; AB07DA2755)	T5	monthly
Lakes		
Kearl Lake (AB07DA2210)	KL1	monthly

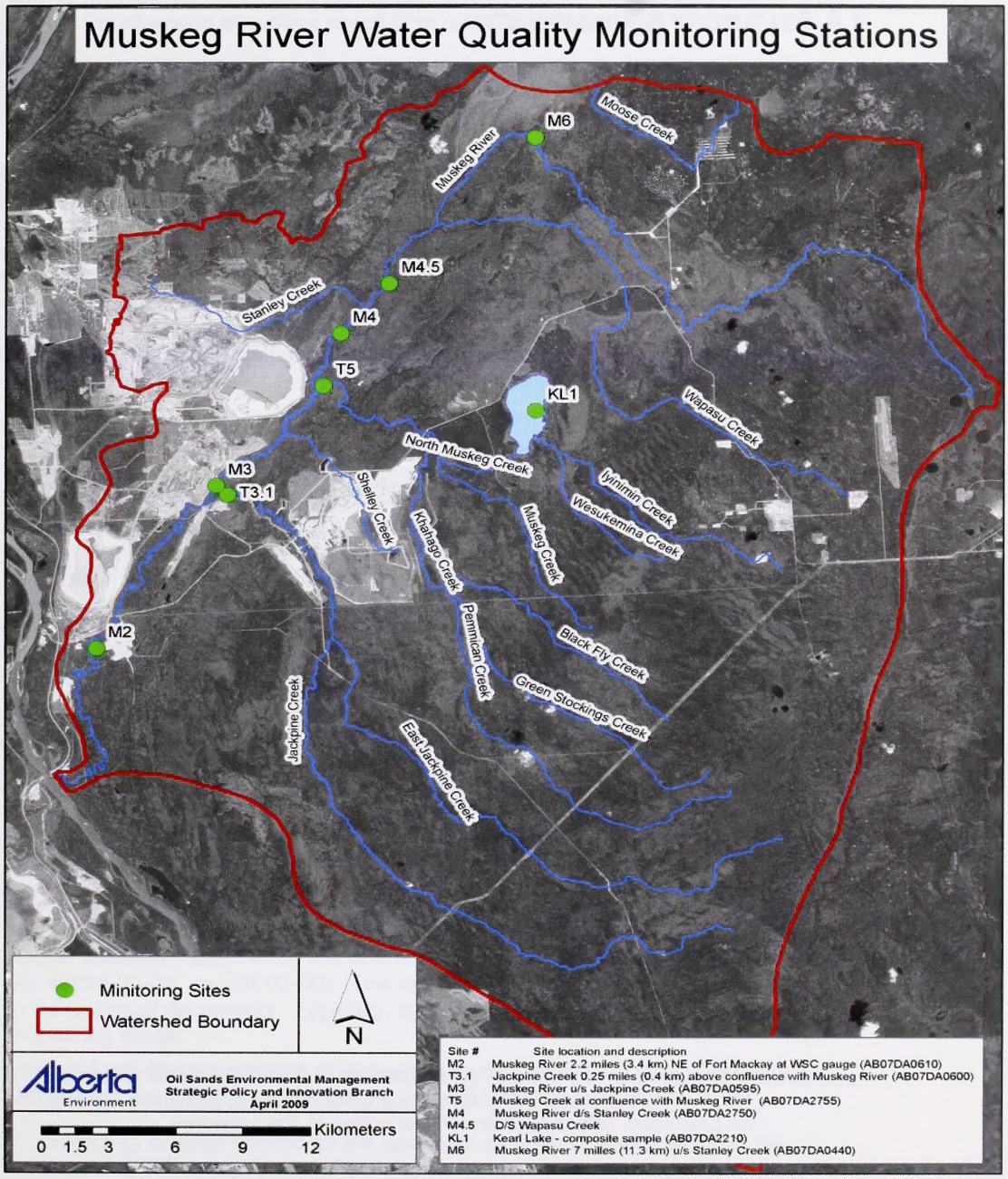


Figure 1. Monitoring sites in the Muskeg River that are part of the Management Framework.

1.4 Statutory Requirements

As mentioned previously, the integrated monitoring program complements and builds on pre-existing monitoring requirements under EPEA and the *Water Act*. Table 2 describes specific industry monitoring sites that are currently incorporated into the integrated monitoring program.

Table 2. EPEA monitoring requirements.

Projects	EPEA Approval #	Sites[1]	Other sites[2]
Imperial Oil Resources Kearl Oil Sands	46586-00-00 S(4.2.7), table 4.2-B	B & C	A
Syncrude Canada Limited Aurora North	26-02-00 S(4.2.20) table 4.2-C	B & C	A & D
Albian Sand Energy Inc. Muskeg River Oil Sands	20809-01-00 S(4.2.7) table 4.2-B	B & C	A
Shell Canada Limited Jackpine Oil Sands Project	153125-00-00	N\A	A

In recognition that a water management framework was required for the Muskeg River basin, Alberta Environment approved the Muskeg River Oil Sands and Kearl Oil Sands projects with the terms and conditions in their EPEA approvals (s4.2.20) supporting the framework's direction:

"*The approval holder shall implement an interim monitoring plan or interim management framework prepared or provided by the Director related to the watershed integrity of the Muskeg River, to satisfaction of the Director*".

Similar terms and conditions were included in the *Water Act* license for Syncrude Canada and Shell Canada, respectively in s3.7 and s3.8 s1(7) and s2(21). The conditions are as follows:

"*The Director reserves the right to establish instream flow needs or other water conservation objectives governing the*

(a) rate of diversion; and,

(b) timing

...diversions from the Muskeg River watershed in accordance with the Muskeg River Interim Management Framework for Water Quantity and Quality (2008), as amended, effective upon written notice to the Licensee.

[1] Sites currently incorporated into the Integrated Monitoring Program.
[2] Individual monitoring sites as specified in the EPEA approvals.

... The Licensee shall comply with the Muskeg River Interim Management Framework for Water Quantity and Quality (2008), as amended, relating to the diversion of surface runoff from within the Fenceline".

2.0 OVERVIEW OF THE EXISTING MONITORING PROGRAMS

The Muskeg River and its tributaries have been monitored periodically under the direction of several independent agencies, including the Alberta Oil Sands Environmental Research Program (AOSERP), the Regional Aquatic Management Program (RAMP), Alberta Environment and industry. This is part of the EPEA approval monitoring requirements and environmental assessment programs associated with oil sands extraction applications. These programs have had different, often complementary objectives, with monitoring being conducted at many different sites within the basin, and often involving analyses of different parameters and media (e.g., water and sediment). The following provides a brief overview of the existing monitoring programs:

1. **Regional Aquatic Management Program (RAMP):** RAMP is a multi-stakeholder regional environmental monitoring program that assesses the health of rivers and lakes in the oil sands region. The primary focus of RAMP is the Athabasca River and its major tributaries in the Athabasca oil sands region. RAMP's work also focuses on the long-term trends, regional issues and potential long-term effects related to industrial development. In addition to its surface water quality monitoring program in the Muskeg River watershed, RAMP works with Syncrude and Albian Sands to monitor polycyclic aromatic hydrocarbons (PAHs) in sediments upstream of the Canterra haul road (near the Water Survey of Canada site) and upstream of Muskeg Creek and Jackpine Creek. In addition, each spring they monitor the sub-lethal toxicity for stream biota upstream of the Canterra haul road and upstream of Jackpine Creek. Thermographs (continuous temperature logging devices) are positioned upstream of Jackpine, Muskeg and Wapasu Creeks. RAMP also monitors Kearl Lake as part of its acid sensitive lakes monitoring program, and conducts periodic sampling of benthic stream macroinvertebrate communities.
2. **Industry Monitoring Programs:** Individual companies conduct site-specific monitoring programs in support of EPEA approval requirements. Approval holders are required "*to conduct aquatic environmental effects monitoring to monitor potential effects on the operation of the plant on the surrounding water and sediment quality, resident aquatic biota including, but not limited to fisheries, benthos and aquatic habitat potentially affected by the operation of the plant*" (EPEA Approvals 20809-01-00, 46586-00-00, and 26-02-00). The monitoring sites and parameters are specified in the approval documents. Typically, the following three sites are required in monitoring plans:
    - Sampling location defined as the discharge point of the sedimentation pond, prior to mixing with the receiving stream (sampling location A sites);
    - Sampling location defined as the upstream sampling location which is the receiving stream upstream of the plant seepages and discharges (sampling location B sites); and,

- Sampling location defined as downstream sampling location which is the receiving stream downstream of the plant seepages and discharges (sampling location C sites).

The analytical package currently used by companies is site specific. Standard surface water quality parameters, including major ions, nutrients, total and dissolved metals, recoverable hydrocarbons, naphthenic acids and phenols are collected.

3. **Alberta Environment Monitoring Program:** Prior to the implementation of the Muskeg River Management Framework, Alberta Environment, in partnership with RAMP, monitored surface water chemistry at three sites along the mainstem of the Muskeg River. In addition to conducting water monitoring under the Framework, Alberta Environment maintains several automated measuring devices that collect basic water quality data (temperature, dissolved oxygen, pH and conductivity) on a continuous basis. In 2009, AENV implemented the Comprehensive Contaminant Load Study (CCLS). In addition to increased sampling frequencies and sites throughout the region, the CCLS also includes the deployment of continuous passive samplers for PAH, naphthenic acid and metals loads in all major tributaries to the lower Athabasca River.
4. **Environment Canada Hydrometric Program:** The Water Survey of Canada (WSC) maintains a long-term hydrometric monitoring station downstream of the Canterra Haul road. Water depth is measured continuously and converted to flow (quantity in m3/s) using a validated stage-discharge formula for open water and under-ice flows.

3.0 FINDINGS AND RESULTS ANALYSIS

3.1 SURFACE WATER QUANTITY

Surface water quantity targets and limits were developed for water level fluctuations at Kearl Lake, flow rates at Muskeg River at site M2, and water diversions in the Muskeg River basin. Compliance with the MRMF was assessed using Kearl Lake water levels collected by RAMP at station L2. Muskeg River flow rates were collected at the Water Survey of Canada (WSC) station 07DA008. WSC operates this station under contract to Alberta Environment during the open-water season. Winter flow data at this location is monitored by RAMP as station S7. The data for water diversions in the basin were gathered from the annual water use reporting requirements under the *Water Act.*

3.1.1 Kearl Lake

Figure 3.1.1 shows the variations in water level at Kearl Lake for 2009 and 2010. The goal of the Muskeg River Water Management Framework is for lake levels to fluctuate naturally around the target level of 331.94 m while remaining above a minimum objective of 331.71 m and below a maximum objective of 332.29 m. The main concerns are the potential for the lake to convert from a lake to a wetland if water levels stay below the minimum level, and to prevent long-term damage to existing wetlands surrounding the lake if water levels were to regularly rise above the maximum level.

Water levels remained between the minimum objective and target levels during 2009 and 2010. The average water level of 331.89 m in 2009 and 331.88 m in 2010 indicates that water levels were below the 1998−2007 average (331.94 m) and well within the range of normal fluctuation. Water levels reached a peak of 332.135 m on July 6, 2009, and a low of 331.785 m on August 24, 2010. The high peak in July 2009 and two moderate peaks in May and September 2010 are consistent with observed flows in the Muskeg River Basin (see section 3.2.1).

Water levels in Kearl Lake fell below the minimum objective level from February 16, 2008, to April 21, 2008. The September 2009 Muskeg River Basin Report recommended future water level data be assessed to determine if water levels continue to decline. The water level data from 2009 to 2010 gave no indication of any decline.

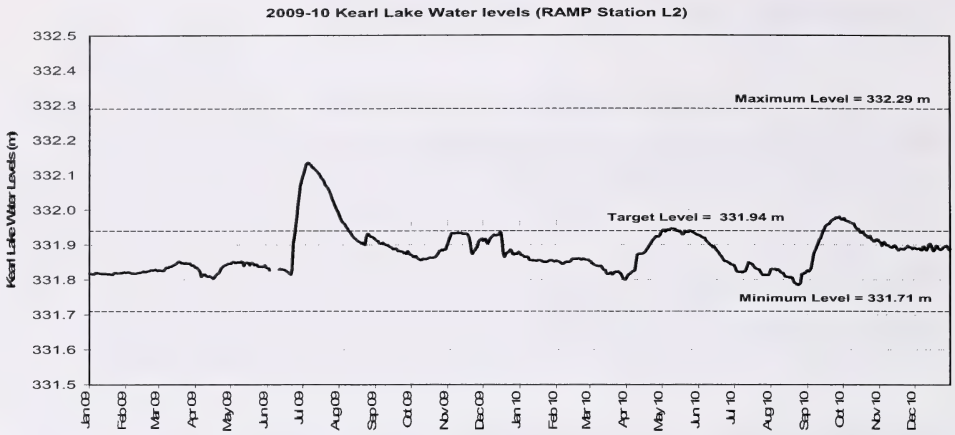


Figure 2. Lake surface elevation or water level (meters above sea level) for Kearl Lake in 2009 and 2010. Data from the Regional Aquatics Monitoring Program (RAMP).

3.1.2 Muskeg River

Figure 3.1.2 shows the variations in flow rate in the Muskeg River for 2009 and 2010. Winter data (November through February) was provided by RAMP. Open water data (March through October) was supplied by the Water Survey of Canada (WSC). The November and December 2010 RAMP data is preliminary and subject to change when RAMP releases its final flow data in 2011.

Under the MRMF, flows are classified on a weekly basis into one of three conditions: Green (normal flows, above the pre-disturbance 80% exceedance flow, licenced diversions have negligible impact), Yellow (low flows, below the pre-disturbance 80% exceedance flow, increased restriction of licenced diversions), and Red (very low flows, below the pre-disturbance 95% exceedance flow, no diversions) (AENV 2008).

Muskeg River flows remained well within the green condition for most of 2009 and 2010, reaching a peak of 42.5 m^3/s on July 3, 2009, and a low of 0.16 m^3/s on December 3, 2009. Flows averaged 4.3 m^3/s in 2009, and 3.0 m^3/s in 2010. The long-term average for the Muskeg River is 4.0 m^3/s. In terms of March to October flows, 2009 and 2010 rank as the 15th and 26th wettest years out of 37 years since flow monitoring began in 1974. The high flow in July 2009 and two moderate flow peaks in May and September 2010 are consistent with observed water levels in Kearl Lake.

Flows dropped to the red level twice in 2009 and twice in 2010. Both years experienced low flows in April due to the delayed onset of snowmelt. Once snow began to melt, flow rates in both years increased rapidly reaching green level by mid April. Flows dropped to the red level for a two-week period in late November and early December 2009, but returned to green levels for the rest of the winter of 2009−2010. The last period in which red conditions occurred was in late July 2010. These low flows were most likely in response to relatively low precipitation in the Lower Athabasca Region in June and July 2010, followed by a second annual peak in September 2010. This flow pattern can be observed in the flow records of several other rivers in the region including the Clearwater, Steepbank, Firebag and Richardson rivers.

Under the MRMF, up to 15% of the flow in the Muskeg River is available for consumptive use under green conditions. Under yellow conditions, use is limited to 5% of the flow and no water should be diverted under red conditions (AENV 2008). However, in 2010 there are no licences in the Muskeg River watershed for direct withdrawals from the Muskeg River. Instead, the primary impact of Oil Sands operations on flows in the Muskeg River is due to land disturbance.

Portions of the Muskeg River watershed have been removed from contributing to flow. These "closed-circuit" areas (see section 3.1.3 Water Diversions) account for licensed water removal from runoff and groundwater. Oil Sands operators also release some water to the Muskeg River system, most notably Syncrude's Aurora Clean Water Diversion that released 5.0 million m^3 in 2009 and 9.3 million m^3 in 2010. In both years, the cumulative effect of Oil Sands activities was to increase winter flows (by 31.6% or more) and low summer flows (by 17.3% or more), and to slightly decrease summer peak flows (by 2.5% or less) (RAMP 2010; RAMP 2011).

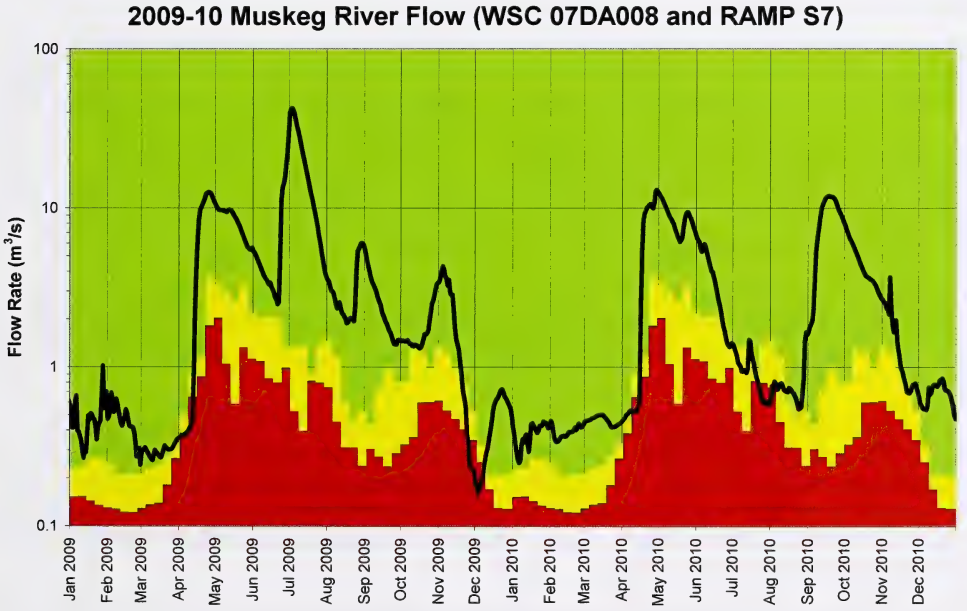


Figure 3. 2009-10 Muskeg River flows and the Muskeg River Water Management Framework green, yellow and red flow conditions. Data sources: RAMP S7 (Jan-Feb 2009, Nov 2009-Feb 2010), WSC 07DA008 (March-Oct 2009, March-Oct 2010), and preliminary RAMP S7 (Nov-Dec 2010). Colours indicate the Green, Yellow, and Red Muskeg River Water Management Framework's flow conditions.

3.1.3 Water Diversions

In 2010, there were four active oil sands mining projects that were licensed under the *Water Act* to divert water within the Muskeg River basin: Syncrude Aurora North, Shell Muskeg River Mine, Shell Jackpine Mine – Phase 1, and Imperial Oil Resources Kearl Oil Sands. None of these projects were licensed to divert water directly from the Muskeg River, and no water intake structures have been constructed along the Muskeg River.

Each of the four active oil sands mining projects has a *Water Act* Licence that authorizes diversions of surface runoff and groundwater within the Muskeg River basin. In addition, in 2010 two temporary diversion licences (TDL) were issued – one for the Syncrude Aurora North project, and one for the Imperial Oil Resources Kearl Oil Sands project. The TDL for Syncrude was for an additional volume of surface runoff and groundwater within the existing project footprint; a review of the water use data showed this TDL was not used in 2010 since the reported annual water use was less than the licensed allocation volume. The TDL for Imperial Oil Resources was for a direct withdrawal from Kearl Lake, which was not included in the *Water Act* Licence as a water source for the project; this water was diverted to fill the fish habitat compensation lake located directly adjacent to Kearl Lake.

Table 3 summarizes the *Water Act* Licence details for each of the four active oil sands mining projects within the Muskeg River basin. This table includes the licensed allocation of surface runoff and groundwater for each project, as well as the allocation volume that was authorized by the two TDLs. The table also provides the monthly water use that was submitted by each oil sands mining project in the annual reports and/or Alberta Environment's online Water Use Reporting system. In addition, the volume of water that was returned to the Muskeg River has been provided on a monthly basis for those oil sands mining companies that are authorized to release water back into the environment.

The monthly withdrawal volume includes water that was diverted as authorized by the two TDLs. In the case of the TDL for the Imperial Oil Resources Kearl Oil Sands project, water was diverted directly from Kearl Lake for only two months, September (11,028 m^3) and October (50,541 m^3).

Table 3 provides the "closed circuit area" for each project in 2010. The closed circuit area is the portion of the project that collects surface runoff without allowing it to drain naturally into the environment. The closed circuit area can be used to estimate or model the volume of surface runoff that would have been released to the natural streams in the absence of the oil sands mining projects. In turn, this assists in assessing the impact the projects have on the Muskeg River.

Some oil sands mining projects have a separate licence allocation for surface runoff and groundwater volumes, and some projects have an allocation for a combined volume of surface runoff and groundwater. Similarly, some of the projects report a combined volume of diverted surface runoff and groundwater, whereas other projects report separate volumes for diverted surface runoff and groundwater. Optimally, each project would have a separate allocation for each source and would also monitor, model, or otherwise estimate and then report a separate diversion volume for each source. To date, it has been adequate to license and report combined volumes for indirect withdrawals from the Muskeg River, but as indicated in the September 2009 document (*Muskeg River Watershed Integrated Water Quality Monitoring Program Annual Report*), the oil sands mining projects should be encouraged to estimate and report surface runoff and groundwater diversions separately

As shown on Table 3, none of the oil sands mining projects had withdrawals that exceeded the *Water Act* Licence allocation volumes. The licenced volumes are set according to the predicted volumes that would have naturally been released to the natural environment from precipitation, and the volume of groundwater that is required to be pumped to prevent mine flooding and protect the geotechnical stability of the mine pits. These volumes are required for mining to proceed and are not optional alternative water use sources. Consequently, if licenced volumes had to be exceeded due to a very wet year or to unexpectedly high volumes of encountered groundwater, a temporary diversion licence would be issued.

Table 3. Monthly 2010 *Water Act* licence allocations, withdrawals and returns.

Project	Syncrude Canada Ltd		Shell Canada Limited		Shell Canada Limited		Imperial Oil Resources	
	Aurora North		Muskeg River Mine		Jackpine Mine Phase 1		Kearl Oil Sands	
Water Act Licence No.	00048398-01-00		00071821-01-00		00186157-00-00		00222199-00-00	
Allocations								
Surface Runoff (SR)	11,580,000		20,230,000		26,000,000		52,000,000	
Groundwater (GW)	8,550,000		(combined with SR)		8,900,000		10,000,000	
Temporary Diversion Licence	2,000,000		0		0		1,200,000	
2010 Closed Circuit Area (km^2)	34.69		38.485		17.7		0	
2010 Withdrawals & Returns	**Withdrawals**	**Returns**	**Withdrawals**	**Returns**	**Withdrawals**	**Returns**	**Withdrawals**	**Returns**
January	1,735,652	885,480	210,289	0	165,066	0	16,212	0
February	1,696,559	912,797	163,500	0	151,514	0	15,581	0
March	1,890,418	1,060,062	164,271	0	158,212	237,284	8,224	0
April	1,788,914	995,973	412,600	0	487,640	209,254	37,453	0
May	1,983,578	868,482	525,242	0	345,371	134,977	68,031	0
June	1,881,881	701,717	404,481	0	163,260	153,774	174,659	0
July	1,754,450	676,253	348,629	0	119,192	107,612	232,619	0
August	1,782,453	605,016	360,722	0	140,265	108,946	183,147	0
September	1,697,701	760,990	941,232	0	643,948	128,588	113,462	0
October	1,560,185	828,523	490,851	0	271,788	62,819	136,387	0
November	1,155,279	906,194	334,687	0	141,606	1,059	16,591	0
December	903,193	947,513	239,802	0	121,782	0	22,540	0
2010 TOTAL	**19,830,263**	**10,149,000**	**4,596,306**	**0**	**2,909,644**	**1,144,313**	**1,024,906**	**0**

3.2 WATER QUALITY

The development footprint in the Muskeg River basin has expanded incrementally since 2008 (from 10% in 2008 to 12% in 2010; RAMP 2011). This expansion was largely associated with the Imperial Kearl Lake project and the Shell Jackpine project, which has since become hydrologically close circuited. The catchments of both of the major tributaries (Jackpine and Muskeg Creeks) have been substantially altered since 2008. The Muskeg River received dewatering flow from site preparation/drainage activities required to create a fish habitat compensation lake for the Shell Jackpine mine beginning in early 2009. Muskeg Creek now flows through the compensation lake constructed in winter 2009-2010 prior to discharging into the Muskeg River. Because the natural outflow for Muskeg Creek was disconnected as a result of the construction of the compensation lake, the sampling point T5 for Muskeg Creek has been relocated to a point in the compensation lake near its outflow.

Surface drainage from the Shell Jackpine mine is directed into Shelley, Khahago and Jackpine creeks. Shelley Creek is a tributary of the Muskeg River. Khahago Creek drains into Muskeg Creek. Surface drainage from the Imperial Kearl mine is directed to a wetland adjacent to the Muskeg River upstream of site M6. Site drainage contains constituents associated with peatlands, shallow groundwater and surface disturbance (e.g. suspended solids). Syncrude also directs surface water that is diverted around its Aurora mine into the Muskeg River by way of Stanley Creek, although this drainage is not presently associated with extensive surface disturbance.

The close circuited mine sites are not sources of direct discharge to the Muskeg River, but may generate seepage of process-affected fluids. Site M3, the Muskeg River above Jackpine Creek, captures impacts from the Syncrude Aurora North mine and large portions of the Shell Muskeg River and Jackpine mine areas. During the 2009 and 2010 Framework years over 80% of site drainage from the Jackpine site passed through Pond 2 into a wetland area in the Shelley Creek basin, ultimately discharging upstream from the M3 site. Jackpine Mine is now effectively close circuited although some release of surface drainage to the Muskeg River continues. Seepages from the Syncrude Aurora mine tailings pond are best captured by water chemistry sampling at M3.

Development of the Imperial Kearl mine and the existence of the Suncor Firebag project effectively invalidates site M6 as a true reference site. The addition of reference sites upstream of M6 is problematic as prospective sites are all within the Imperial Kearl development footprint or are situated too high in the watershed to serve as suitable reference sites. However, the need for suitable reference sites in the context of the Imperial Kearl project necessitates the establishment of a site upstream of site M6.

3.2.1 Framework Triggers and Limits

Table 4 summarizes mean and peak values for all parameters sampled in 2009 and 2010, and compares them with 2008 data and water quality triggers and limits contained in the MRMF. The limits presented in the Framework are based on guidelines for protection of the most sensitive uses, primarily the protection of aquatic life. Limits apply throughout the system unless they are exceeded naturally by background conditions. However, reporting under the Framework is against conditions at site M2 only. All

assessments are based on the period between April and March of the following year, referred to as the framework year.

Table 4. Muskeg River Management Framework trigger and limit exceedances.

General Chemistry and Nutrients

Water Quality Parameter	Units	Measured Mean (2008)	Measured Mean (2009)	Measured Mean (2010)	WQT Mean Target (Yellow)	Measured Peak/Max (2008)	Measured Peak/Max (2009)	Measured Peak/Max (2010)	WQT Peak Target (Yellow)	WQL Mean Limit (Red)	WQL Peak Limit (Red)
Temperature	C				10.6	22.97	19.9	24.07	25.3	RSWQO	RSWQO
Chlorophyll a	mg/m^3	0.83			5	2.8			12	NA	NA
Total Kjeldahl Nitrogen	mg/L	0.896	0.978	0.968	1.3	1.24	1.36	1.17	3.5	RSWQO	NA
Nitrate + Nitrite	mg/L	**0.032**	0.028	**0.031**	0.03	0.087	0.149	0.077	0.362	RSWQO	29000
Ammonia	mg/L	0.166	0.153	0.15	0.179	0.56	0.54	0.39	0.718	500	2400
Total Phosphorus	mg/L	0.038	**0.048**	0.033	0.042	0.099	0.069	0.066	0.219	50 (RSWQO)	NA
Dissolved Organic Carbon	mg/L	22.4	21.5	21.3	25.6	27.8	31.1	27.8	63.1	NA	NA
True Colour	TCU	**86**	**96**	**114**	63	137	**190**	**210**	115	NA	NA
Total Alkalinity ($CaCO_3$)	mg/L	188.9	193.2	195.4	225.3	298	308	265	398.1	NA	NA
Chloride	mg/L	3.9	4.2	3.8	5.4	13.6	10.3	5.2	34.1	230	250
Sulphate	mg/L	2.5	11	6.3	11.4	8	18	13	106.5	500	500
Specific Conductance (field)	µS/cm	349	365		381	560	552		806	NA	NA
Conductivity (lab)	µS/cm	362	380	372	418	578	572	508	799		
pH (field)	pH units	7.5	7.5	7.7	6.5, 9.2	8.3	8.1	8.3	6.0, 10.8	6.5	RSWQO
Biochemical Oxygen Demand	mg/L	**1.8**	**1.8**	1.1	1.4	**3.4**	**3.2**	1.7	2.4	Based on DO	
Chemical Oxygen Demand	mg/L	56.9	49.2	47.5	75.6	69	56	61	221.3	Based on DO	
Dissolved Oxygen (meter)	mg/L				Saturation	0.94	0	1.32	1.44[m]	6.5*	5*
Total Suspended Solids	mg/L	3.5	5.5	2.4	6.5	16	15	5	82.2	NA	NA
Turbidity	NTU	6	8	5	9	17	17	10	77	NA	NA
Oil and Grease	mg/L	**3**			1.09	3			4.17		

Metals

Water Quality Parameter	Units	Measured Mean (2008)	Measured Mean (2009)	Measured Mean (2010)	WQT Mean Target (Yellow)	Measured Peak/Max (2008)	Measured Peak/Max (2009)	Measured Peak/Max (2010)	WQT Peak Target (Yellow)	WQL Mean Limit (Red)	WQL Peak Limit (Red)
Aluminum (total)	mg/L	**0.088**	**0.13**	0.052	0.061	**0.54**	**0.418**	**0.243**	0.162	ASWQG variable	RSWQO
Arsenic (total)	mg/L	0.0003	0.0004	0.0003	0.0004	0.0005	0.0005	0.0004	0.0009	RSWQO	0.005
Boron (total)	mg/L	0.047	**0.052**	0.044	0.05	0.062	**0.076**	0.051	0.07	0.055	0.5
Barium (total)	mg/L	0.044	0.048	0.048	0.084	0.073	0.087	0.066	0.138	0.088 (RSWQO)	1
Cadmium (total)	mg/L	0.00001	0.00001	0.00001	ID	0.000004	0.000005	0.000002	0.00003	ASWQG variable	0.0011
Chromium (total)	mg/L	0.0003	0.0003	0.0002	0.0007	0.0006	0.0006	0.0005	0.0034	0.008	0.0089
Copper (total)	mg/L	0.0002	0.0003	0.0002	0.0005	0.0005	0.0005	0.0003	0.0008	0.007	0.17
Iron (total)	mg/L	0.968	**1.194**	0.958	1.0218	1.86	1.79	1.61	2.6364	NG	RSWQO
Mercury (total)	ng/L	1.03	1.25	0.34	ID	**2.98**	**3.04**	0.68	2.18	5	13
Lithium (total)	mg/L	0.0101	0.0115	0.009	0.0119	0.0143	**0.0228**	0.0114	0.0154	NG	NG
Manganese (total)	mg/L	0.2175	**0.274**	0.1254	0.2359	1.11	1.01	0.45	1.2732	0.39	RSWQO
Molybdenum (total)	mg/L	0.0001	0.0001	0.0001	0.0002	0.0003	0.0002	0.0001	0.0003	0.028	0.73
Nickel (total)	mg/L	0.0004	0.0004	0.0002	0.0006	**0.0015**	0.0013	0.0005	0.0013	0.0072	0.062
Lead (total)	mg/L	0.0001	0.0001	0.00004	0.0001	**0.0002**	**0.0002**	0.0001	0.0001	0.001	0.002
Tin (total)	mg/L	0.00003	100%<MDL	0.00002	ID	0.0001	100%<MDL	0.0001	ID	0.0022	0.51
Selenium (total)	mg/L	0.0001	0.0001	0.0001	ID	0.0003	0.0004	0.0002	0.0007	RSWQO	0.001
Strontium (total)	mg/L	0.128	0.143	0.131	0.224	0.182	0.238	0.182	0.26	3.3 (RSWQO)	NG
Vanadium (total)	mg/L	0.0004	0.0005	0.0003	0.004	0.001	0.001	0.0005	0.013	0.017	0.16
Zinc (total)	mg/L	**0.0011**	**0.0014**	**0.0014**	0.004	**0.0025**	**0.004**	**0.004**	0.0006	RSWQO	0.03

Organics

Water Quality Parameter	Units	Measured Mean (2008)	Measured Mean (2009)	Measured Mean (2010)	WQT Mean Target (Yellow)	Measured Peak/Max (2008)	Measured Peak/Max (2009)	Measured Peak/Max (2010)	WQT Peak Target (Yellow)	WQL Mean Limit (Red)	WQL Peak Limit (Red)
Acenaphthylene	µg/L	100%<MDL	100%<MDL	100%<MDL	80% <MDL				0.042	NA	5.8
Benzo(a)anthracene	µg/L	100%<MDL	100%<MDL	100%<MDL	80% <MDL				0.0036	NA	0.018
Benzo(b,j,k)fluoranthene	µg/L	92%<MDL	92%<MDL	100%<MDL	80% <MDL	**0.015**	**0.015**		0.0108	NA	NG
Benzo(g,h,i)perylene	µg/L	92%<MDL	92%<MDL	100%<MDL	80% <MDL	**0.009**	**0.009**		0.0024	NA	0.0152
Chrysene	µg/L	100%<MDL	92%<MDL	100%<MDL	80% <MDL		**0.016**		0.0048	NA	NG
Dibenz(a,h)anthracene	µg/L	100%<MDL	100%<MDL	100%<MDL	80% <MDL				ID	NA	NG
Fluoranthene	µg/L	100%<MDL	100%<MDL	100%<MDL	80% <MDL				0.0048	NA	0.04
Fluorene	µg/L	100%<MDL	100%<MDL	100%<MDL	80% <MDL				0.0192	NA	3
Indeno(1,2,3-c,d)pyrene	µg/L	100%<MDL	92%<MDL	100%<MDL	80% <MDL	**0.007**	**0.007**		0.0048	NA	NG
Napthalene	µg/L	100%<MDL	**0.017**	100%<MDL	80% <MDL				1.068	NA	1.1
Phenanthrene	µg/L	92%<MDL	**0.007**	100%<MDL	80% <MDL	**0.007**	**0.01**		0.0144	NA	0.4
Pyrene	µg/L	100%<MDL	92%<MDL	100%<MDL	80% <MDL		**0.003**		0.0048	NA	0.025

The triggers are site specific and were developed for the WSC gauge site (site M2); they are not directly applicable to sites upstream. This approach reflects an expectation that some constituents (e.g., phosphorus, magnesium, titanium, etc.) are present at higher concentrations in tributaries or at upstream sites and are attenuated through the river continuum, either through dilution or instream processes (uptake, sedimentation and transformation). As well, AENV accepts there will be localised change in water quality associated with development in the Muskeg River watershed. In this context, the intent of the Framework is to protect the water quality at site M2 and by extension, protect water quality in the Athabasca River. Water quality at all sites is discussed within the context of the M2 site triggers as a reference point, but the triggers apply only to site M2 for the MRMF.

Monitoring at site M2 during the 2009 and 2010 Framework years demonstrated that concentrations of most constituents are consistent with historic concentrations. Exceptions are nitrate−nitrite (NO2−NO3), total phosphorus (TP), true colour and biochemical oxygen demand (BOD), as well as several metals (Al, B, Fe, Li, Mn, Hg, Ni and Zn). Aluminum also exceeded the mean limit during the 2009 Framework year, indicating the potential for chronic stress to ecological receptors. Polycyclic aromatic hydrocarbons exceeded Framework targets in the 2008 and 2009 Framework years but not in 2010.

Several of the exceedances of inorganic triggers may be attributable to development in the watershed. Exceedances of the aluminum targets, in particular, suggest loading from disturbed areas. Loading of boron and lithium may also be attributable to development, possibly from enhanced seepage. It is unclear whether exceedance of the true colour targets reflects development related to loading or a long-term trend. Additional work in this area is required to better understand these exceedances.

3.2.1.1 Limits

Limits adopted under the MRMF reflect the established guidelines (whether Alberta Surface Water Quality Guidelines, Canadian Council of Ministers of the Environment (CCME), or extra-jurisdictional) for protection of the most sensitive use. To the extent that constituent loads are attributable to development, exceedance of limits under the Framework necessitates loading reductions.

No peak limits were exceeded during the 2009 and 2010 framework years. Mean limit exceedance of the aluminum limit of 0.1 mg/L (pH≥6.5) was observed during the 2009 Framework year (mean Al total 0.130 mg/L). This exceedance is associated with discharge events, particularly rainfall events that generated higher than normal flows in early July and late August. Elevated concentrations of total aluminum are not uncommon in the historic record for this site and are usually associated with higher than normal discharge events. Mean aluminum concentrations returned to historic levels in 2010.

It is unclear whether the elevated total aluminum concentrations observed at site M2 are related to development. In some instances, elevated concentrations observed at site M2 appear to be directly related to loading of total aluminum from the tributaries. In April 2009, the total aluminum load from T3.1 (Jackpine Creek) was 529 kg/d, whereas the load at site M2 was 415 kg/d. Elevated concentrations observed during this sampling event at site M2 are likely attributable to loading from Jackpine Creek. Both tributaries are directly impacted by early phases of mine development. Ponds 3 and 6 release directly to Jackpine Creek. However, sampling of Pond 6 in May 2009 indicates

relatively low total aluminum concentrations (0.054 mg/L) suggesting that the elevated aluminum concentrations in spring of 2009 cannot be directly attributed to site dewatering. Nonetheless, in May 2009 total aluminum concentrations at site T3.1 (Jackpine Creek near the mouth) were substantially higher (0.248 mg/L) than at Shell's monitoring site upstream of the Jackpine Mine (0.095 mg/L), indicating a substantial total aluminum load in the lower Jackpine Creek watershed. This large relative difference in total aluminum concentrations at upstream and downstream sites in Jackpine Creek does not recur in the sampling record suggesting either that the elevated total aluminum load occurs only during periods of elevated discharge or that it represents a transient event. There are several potential conduits for the conveyance of surface erosion from the Jackpine Mine site, its main access road and the utility corridor adjacent to Jackpine Creek into Jackpine Creek. Preliminary visual surveys suggest that these conduits are located downstream of the access road. The effect of flow augmentation in Jackpine Creek using Athabasca River water is also unknown. Focused sampling should be undertaken in Jackpine Creek to evaluate the extent of potential inputs associated with flow augmentation and erosion.

Operators have reported difficulty in attenuating the flux of very fine suspended material (presumably colloids and clays) through settling ponds. Given that aluminum tends to form fine colloids and is a component of many clays, exceedance of the total aluminum limit during the 2009 Framework year may also be associated with this issue. A detailed loading assessment would assess the extent to which the observed exceedance of the total aluminum limit is attributable to development-related disturbance. Alberta Environment will work with industrial operators over the next year to determine the best approach to further this investigation.

The response of operators to the problems posed by the flux of very fine particles through their retention ponds has been to reduce direct releases to the Muskeg River and its tributaries. Instead, releases are directed to wetlands where lower velocities and several filtering pathways facilitate the settling of very fine particles. Continued monitoring during the 2011 framework year will demonstrate whether exceedance of the total aluminum limit observed in 2009 has thus been mitigated.

The Water Quality Framework for the Lower Athabasca River Regional Plan does not specify a total aluminum limit, recognising that the sensitive use-protection guideline is exceeded under natural conditions and that a site-specific limit must be developed. Given that natural exceedances of the mean limit for total aluminum have been observed at site M2 (0.107 mg/L in 1979, 0.158 mg/L in 1980), a similar approach may be appropriate under the MRMF.

3.2.1.2 Triggers

Mean and peak triggers are calculated from background (pre-2008) data with an allowance of 20%, reflecting an anti-degradation approach. Exceedance of the triggers does not necessarily indicate ecological impact but is an indicator of change that requires additional investigation and possibly mitigation.

Water quality triggers for a number of water quality parameters measured at site M2 were exceeded in the 2009 and 2010 Framework years (Table 4). As in 2008, a number of low risk (routine) indicators exceeded the mean water quality targets in 2009 and 2010. Total phosphorus, true color, and biochemical oxygen demand (BOD) exceeded mean targets in the 2009 Framework year, and nitrate−nitrite and true colour exceeded

mean targets in the 2010 Framework year. True colour and BOD exceeded the peak target in 2009, and only true colour exceeded the peak target in 2010.

The consecutive exceedances in 2008, 2009 and 2010 of the mean target for true colour, and the exceedances in 2009 and 2010 of the peak target, suggest a departure from the natural condition. The mean and peak values also increase sequentially from 2008 through 2010. Peatland drainage prior to mine excavation is assumed to be the primary source of any development-related loadings of true colour.

True colour is generally higher in tributaries T3.1 and T5 than at site M2. However, this is not necessarily indicative of an inordinate contribution from these tributaries. As well, the time trend extends at least to 1998, indicating progressive change that may not be development related. Although true colour is correlated with constituents such as arsenic and dissolved organic carbon, and inversely correlated with major ions, these co-variates do not show similar temporal trends.

The mean and peak target exceedances for total phosphorus, nitrate−nitrite and biochemical oxygen demand (BOD) may also be related to peatland dewatering, but do not show the distinct temporal trend apparent in the true colour data. These parameters tend not to occur at significantly higher concentrations in tributaries T3.1 and T5 to the degree that their contribution to the total load at site M2 is out of proportion with other sources. Shell reported high (11.1 mg/L) BOD concentrations in Pond 2 in August 2009. They concluded that the high BOD was associated with high rates of interflow from peatlands following unusually high rainfall in 2009. This is supported by observations of high BOD Muskeg Creek (8.8 mg/L), Jackpine Creek (5.2 mg/L) and Muskeg River (9.3 mg/L) in August 2009.

Several metals also exceeded the mean water quality triggers in 2009: aluminum, boron, iron, manganese and zinc. Only zinc exceeded the mean trigger in 2010. Peak triggers for aluminum, boron, mercury, lithium, lead and zinc were exceeded in 2009. Only aluminum and zinc exceeded peak triggers in 2010. The exceedances of the aluminum and lead triggers may reflect the dewatering of development areas prior to mine excavation as discussed in relation to the exceedance of the aluminum limit.

Exceedances of the mean and peak triggers for boron and the peak trigger for lithium are noteworthy because both metals have been tentatively linked with oil sands-related seepage (van den Heuvel et al. 1999). The peak triggers are particularly important for these metals as development-related inputs would most likely be detected only during periods of low discharge, as in February and March 2010 (see discussion of temporal patterns, section 3.2.2.1). Exceedance of the lithium and boron triggers appears to be related to elevated concentrations in Jackpine and, to a lesser extent, Muskeg Creek. As boron concentrations tend to be elevated in pond 2, the exceedances are probably development-related.

The exceedances of the mean and peak triggers for zinc are probably artifacts of the triggers themselves, which fall considerably below the mean value for the available data. The iron and manganese concentrations are also not unusually elevated when considered in the context of the historic record. The mercury triggers, which are based on number of values above the method detection limit, were developed prior to the adoption of the ultra trace methodology in 2008. At the time of their development, exceedances of the detection level of 5 ng/L were rare and the trigger was appropriately protective. Indeed, when the data collected at the ultra trace level (MDL 0.03 ng/L) are assessed against the previous detection limit of 5 ng/L, mercury does not exceed the

triggers in 2008–2010. As with zinc, iron and manganese, exceedances of the mercury trigger appear to be artifacts of the triggers themselves. These triggers will be reviewed before releasing the 2011 Muskeg River monitoring report.

Mean targets for hydrocarbons are based on the frequency of detection; peak targets are derived in the same manner as those for other parameters. Mean water quality targets were exceeded for naphthalene and phenanthrene in 2008 only. Peak targets for benzo(b,j,k)fluoranthene, benzo(g,h,i)perylene, chrysene, indeno(1,2,3-c,d)pyrene, phenanthrene and pyrene were exceeded in 2009. With the exceptions of benzo(b,j,k)fluoranthene and phenanthrene, the peak targets for all these constituents are all lower than their respective analytical detection limits (0.01 ug/L). Only benzo(b,j,k)fluoranthene and chrysene were detected at concentrations greater than their detection limits. The exceedances of the peak targets for the other constituents are clearly artifacts of the triggers themselves. No peak targets were exceeded in 2010.

3.2.2 Non-Framework Water Quality Changes at Performance Assessment Site (M2)

In addition to the relevant framework triggers and limits, there are several indicators of development-related influence on water quality at site M2 in 2009. These indicators fall into two general categories: those that are particulate-related and those that are seepage related. The former are most notable in samples collected in April and June 2009 whereas the latter are most notable in March 2010. Particulate-related parameters include aluminum, particulate carbon, titanium, total suspended solids and vanadium. Seepage-related parameters include boron, bismuth, chloride, cobalt, copper, potassium, molybdenum, nickel, phosphorus, lead, antimony, selenium, titanium, uranium and zinc. The source of these constituents is clearly Jackpine Creek (T3.1) and is presumably associated with surface dewatering at the Jackpine mine. The impact of the particulate-related parameters is associated with elevated flows at the time of sampling in April and June, suggesting erosive inputs. It is not clear why the seepage-related parameters were present in elevated concentrations in March 2010, although these may be related to altered groundwater flow paths associated with flow augmentation and aquifer depressurisation.

These findings necessitate a thorough evaluation of loadings to Jackpine Creek. Even though these impacts remain small and within limits for sustainable development in the region, the management response must be:

- to further evaluate the sources of the particulate and seepage related loads,
- to evaluate related risks to the aquatic ecosystem, and
- to consider appropriate management action where loads are found to be associated with development-related disturbance and where risks are deemed to be unacceptable.

Low flows in June, July and August 2010 caused slightly higher than average concentrations of base-flow related (deep groundwater and seepage from peatlands) parameters (alkalinity, specific conductance, TDS, Ba, colour etc.) during the 2010 Framework year (Appendix 1). This change does not appear to be related to development.

In addition to recent variability associated with hydrology or development, there appears to be a long-term increasing trend in colour. This trend extends at least back to 1998, prior to extensive mine development in the catchment. The trend does not occur for any

other parameter including those that show similar seasonal patterns (As, DOC, pH and Sb), notwithstanding that the presumed source of the colour is dissolved organic matter. The likely cause of the colour trend is change within the peatlands, whether through change in organic matter oxidation, frost penetration or hydrology. The ultimate driver may be climate related.

3.2.2.1 Seasonal Trends

The sub-annual distributions of metal concentrations fall into four general patterns. The first pattern typically entails a peak following ice-out (April-May) which is usually followed by a rapid decline, although additional peaks are not uncommon during the ice-free season (Figure 4). This pattern appears to be associated with the suspended solids load and discharge and is typical of aluminum, mercury, dissolved magnesium, molybdenum, total lead and total vanadium, particularly the total (unfiltered) fraction (with the exception of Mg). The concentration of the dissolved fraction (Al, Mo) and total thorium tends to decline more gradually, indicating this pattern is not strictly flow dependent although it may reflect the re-suspension or more gradual settling of the colloidal fraction following a high flow event.

The second general pattern is a mid-winter (December-February) peak typical of barium, chloride, cobalt, manganese and titanium (Figure 5). The source of this pattern is unclear although it may relate to flow pathways through peatlands, which change seasonally in relation to frost penetration. The third pattern is a peak prior to ice-out (usually March) often with a minor peak in late summer, typical of calcium, boron, cadmium, lithium, magnesium, strontium, uranium, and zinc (Figure 6). This pattern appears to be inversely related to discharge and may be associated with groundwater seepage.

The final pattern is a mid-summer (June-August) peak typical of aresnic and antimony (Figure 7). This pattern is correlated with dissolved organic carbon, suggesting that these metals are associated with and possibly mobilised by dissolved organic carbon and that this pattern relates to interflow from peatlands. This pattern is presumably regulated by the frost cycle such that the depths of the upper and lower boundaries of the frost layer regulate flow through the peatlands. Several metals exhibit no discernable seasonal patterns (Be, Bi, Cr, Cu, Fe, Pb, Ni, Se, Ag, Th and Sn), possibly because they have multiple sources.

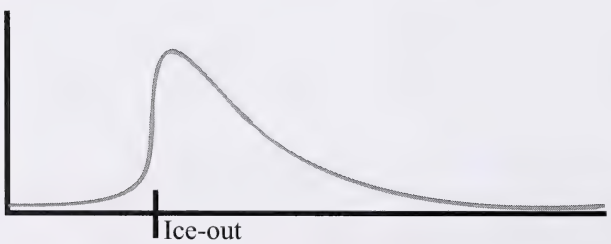


Figure 4. Type 1 seasonal pattern, peak concentration following ice-out.

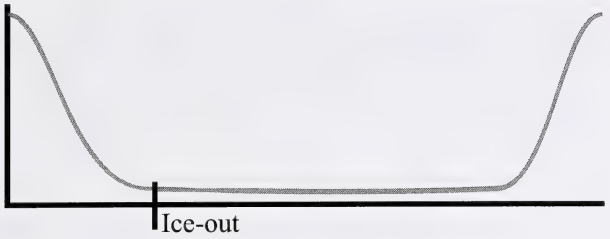


Figure 5. Type 2 seasonal pattern, mid-winter peak concentration.

Figure 6. Type 3 seasonal pattern, peak concentration prior to ice-out.

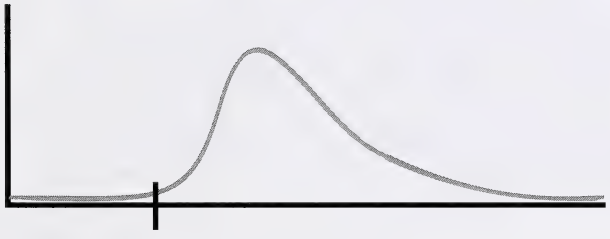


Figure 7. Type 4 seasonal pattern, mid summer peak concentration.

The sub-annual distributions of inorganic constituents fall into three of the four general patterns identified in the metals. Total dissolved solids, turbidity and total phosphorus follow the first pattern which appears to be discharge related. Alkalinty, major ions (Cl, HCO3, Ca, K, Mg, Na), ammonia, hardness, nitrate/nitrite, total kjeldahl nitrogen, silicon, and conductivity follow the third pattern and are presumably groundwater related. Dissolved organic carbon, colour and pH follow the fourth pattern and are believed to reflect interflow through peatlands.

Primary productivity (measured as phytoplankton Chl-*a*) is not strongly correlated with either phosphorus or nitrogen. This is probably because the system is light limited and the phosphorus is correlated with flow and turbidity which vary in inverse relation to Chl-*a*.

Arsenic is strongly correlated with Chl-*a*. This may be related to the competitive uptake of arsenic and phosphorus by primary producers, or may simply reflect seasonal covariance. Total arsenic is also strongly correlated with dissolved organic carbon, both

of which vary according to the type four pattern discussed previously. Therefore, it is equally possible that arsenic is mobilised by dissolved organic carbon (e.g., Bauer and Blodau 2006), and that the correlation with Chl-*a* is entirely incidental. It is clear from the seasonal pattern that arsenic is not associated with groundwater seepage, whether natural or anthropogenic.

3.2.2.2 Mercury

Special attention has been directed toward the occurrence of mercury in surface waters in the lower Athabasca region. Usually the mercury concentrations in the Athabasca River and its tributaries are below the detection capability of the standard ICP-MS scan for metals and also below the low-level mercury analysis by atomic absorption spectroscopy. However, the tendency of mercury to bioaccumulate and biomagnify makes it necessary to quantify mercury at ambient concentrations. Therefore, the management framework monitoring program uses ultra-low level analysis by atomic fluorescence spectroscopy (0.03 ng/L MDL).

The adoption of ultra trace analysis for mercury makes it more difficult to compare monitoring framework data with historical data. Data collected from 2003, when low-level mercury analysis was first adopted, through 2007 remain useful but there is a distinct step in the data associated with the previous method detection limit of 5 ng/L. Consequently, only the data analysed at ultra trace concentrations have been assessed in this report. This issue is common to all long-term monitoring programs and is a necessary consequence of a commitment to continuous improvement.

Mercury is strongly correlated (r=0.72) with suspended solids and follows a type 1 temporal distribution, which is discharge related. Mercury is uncorrelated with DOC, suggesting the major source is not mobilisation in peatlands (e.g., by methylation). Although there are regional sources of mercury, the mobility and transport of mercury in local catchments has not been characterised. The relatively low concentrations of mercury measured in the Muskeg River preclude assessment of temporal trends, since these levels are consistently below historical detection levels.

The peak total mercury concentrations observed in the Muskeg River at M2 were 3 ng/L in 2009−2010 and 1.02 in 2010−2011, well below the draft provincial guideline of 13 ng/L (acute). The mean total mercury concentrations of 1.03 ng/L (2009−2010) and 0.33 (2010−2011) were also well below the provincial guideline of 5 ng/L and less than average mercury concentrations in the lower Athabasca River. Jackpine Creek and Muskeg Creek are not important sources of mercury. There are no longitudinal trends (Fig. 10).

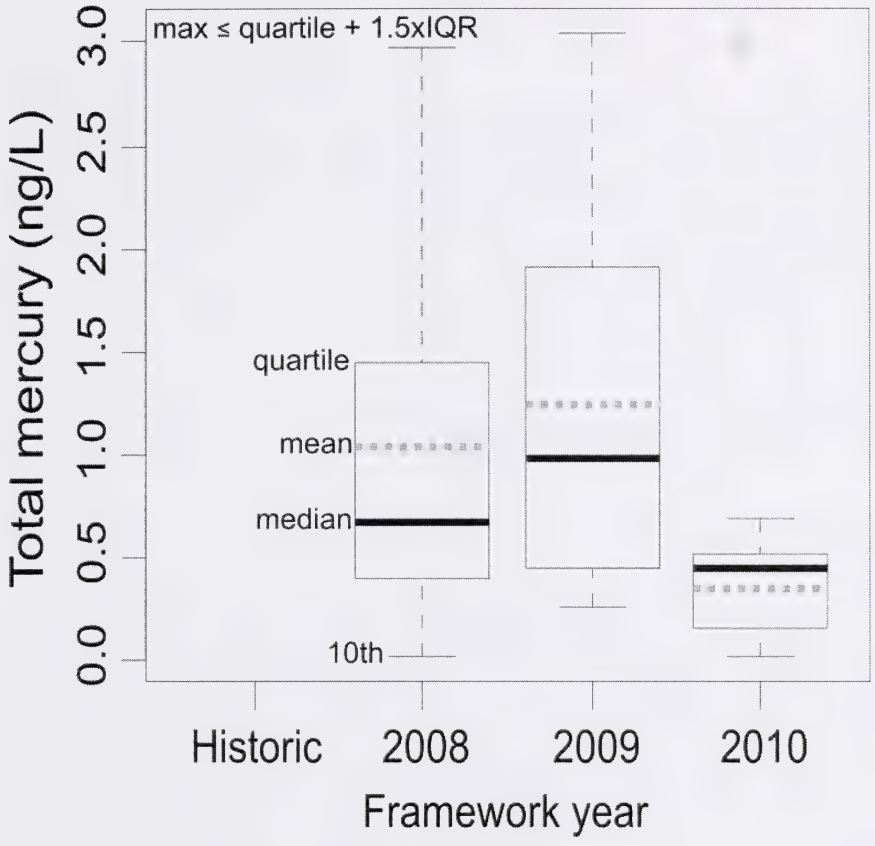


Figure 9. Mercury concentrations at the M2 site. Historic data are excluded because the detection level was unacceptably high (5 ng/L)

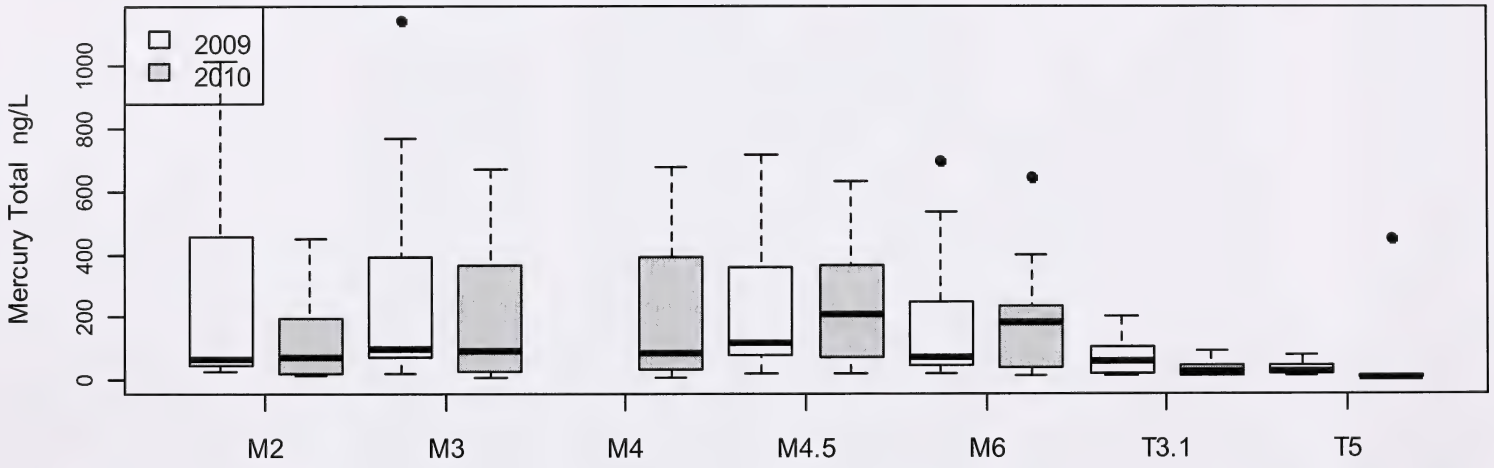


Figure 10. Total mercury concentrations in 2009 and 2010 at all sites.

3.2.2.3 Upstream to Downstream

The Muskeg River system does not contain any true reference sites against which potentially impacted sites can be compared. This is in part because resource development occurs throughout the basin; the Imperial Kearl oil sands mine and the Husky Sunrise in situ project are located along the Muskeg River channel upstream of site M6. This portion of the Muskeg River will be substantially altered in the course of the development of the Imperial Kearl oil sands mine, so any upstream reference site will be short lived. Imperial began commercial operations at the Kearl oil sands mine involving drainage and soil salvage in 2008, which was the first year of monitoring under the framework. The area and location of these disturbances, which is between 2.5 and 6 km northeast of site M6, could impact the water chemistry at this site. As well, atmospheric deposition of oil sands-related contaminants effectively invalidates any site in the lower Athabasca River area as a true reference site, although the importance of this vector relative to contaminant loading has yet to be established.

The geologic and physiographic setting also differs substantially from upstream to downstream. The Muskeg River channel upstream of site M6 originates from a topographic high (Muskeg Mountain) as a fimbriate series of tributaries and then meanders though fen and beaver ponds, occasionally becoming lost from sight altogether. The middle portion of the Muskeg River between sites M6 and M4 has relatively little gradient, forming a more defined channel through a bog-dominated landscape. The lower portion of the Muskeg River passes over a higher gradient (especially downstream of site M2) as it flows across the Athabasca River escarpment.

The location of the Muskeg River with respect to surficial geology and local groundwater is also a key consideration. The Muskeg River flows through three distinct geologic outcrops, beginning with the Grand Rapids Formation in the headwaters, flowing though the Clearwater Formation upstream of site M6 and finally into the ore-bearing McMurray Formation. The topographic high (Grand Rapids Formation.) in the southeastern portion of the catchment is also an important recharge zone, discharging lower in the catchment according to the topographic gradient. Sediments at sites M6 through M4 consist of organic soils whereas sediments at sites M2, T3.1 and M3 are coarse sand and cobble.

The monitoring sites are all located within the bitumen-bearing McMurray formation. Sites M2, M3 and T3.1 flow through the ore bearing McMurray formation, and bitumen ore is abundant along the banks. As such, a background of bitumen-related contaminants is expected, although the bitumen content within the McMurray formation varies considerably. As well, the potentiometric surface of the McMurray aquifer is very near the ground surface in the region of the lower Muskeg River downstream of site M6, where the basal aquifer is also relatively thick (>10 m; Hackbarth and Nastasa 1979). The influence of seepage from the McMurray aquifer is clearly reflected in the water chemistry of the lower Muskeg River, particularly in winter.

As an alternative to the reference condition approach, a river continuum approach was adapted whereby changes in constituent concentrations are assessed relative to presumed longitudinal gradients. Anthropogenic impacts are overprinted on these longitudinal gradients as abrupt change(s) among sites, especially in relation to the location of major oil sands projects.

The conceptual framework for interpreting the water chemistry data entails a gradation from edaphic to groundwater influence. The upper portion of the Muskeg River (above site M6) is more likely to be influenced by factors associated with peatlands, specifically the reduction of organic matter within the active layer (acrotelm), whereas the lower portion of the Muskeg River is increasingly influenced by groundwater. This may change in the development context as the McMurray aquifer is depressurised, potentially leading to change(s) in local flow pathways. The presumed effect on the Muskeg River would be a decline in the groundwater signature, although this may be offset by the short circuiting of surficial drainage areas.

Overlaid on the hydrologic, edaphic and hydrogeologic factors is the direct contact of the river with the ore body and accretion of related contaminants in bed sediments. This is the most commonly identified exposure pathway (e.g., by erosion of the ore body) but perhaps the least well characterised. Bitumen is clearly present in Muskeg River sediments (e.g., RAMP 2010), particularly toward the mouth where the energy of the system becomes dissipated and the sediment burden can then settle. The result is a focusing of this load at the mouth of the river, making it more difficult to interpret the longitudinal survey of sediment contaminants, and presumably the surface water contaminants.

The historical (based on the complete data record) water chemistry gradient in the Muskeg River is characterised by an increase from upstream to downstream in sodium, chloride, boron (total) and lithium (dissolved), which are all indicative of an increasing groundwater component. Alkalinity does not increase longitudinally as might be expected with a typical carbonate groundwater system, but actually appears to decline slightly. This may be related to the increasing chloride or dissolved organic carbon concentration. There is also an increase in several dissolved metals (aluminum, lead) that may be related to the particulate phase. All these parameters are present in higher concentration in Jackpine Creek (T3.1) and Muskeg Creek (T5).

Total phosphorus declines from sites M6 through M2, suggesting either that it is removed from the water column or that the most important influence is at the upstream sites, presumably originating from the marine shales of the Clearwater Formation or mobilised within peatlands (e.g., through competitive binding of iron with reduced sulphur). Nonfilterable residue (total suspended solids) remains relatively unchanged as does total aluminum, a typical covariate of the nonfilterable component that is indicative of suspended clays. Most parameters are more variable at site M2, likely a product of seasonal patterns.

The longitudinal gradient during the 2009 and 2010 framework years is characterised by an increase from upstream to downstream of a number of the parameters identified in the temporal assessment for site M2 (e.g., Al, B, Cl, Na, Pb, Sb, U), and some that are not (As, Ba, Cd, Cr, Li, Mg, SO4). The concentrations of all of these parameters are also elevated at the tributary sites. Arguably, this is consistent with the river continuum concept in that the tributary sites, as well as the Muskeg River sites located downstream of them, are located at similar points within the watershed. In addition, constituent concentrations that are lower at sites M2 and M3 than at upstream sites are typically also lower at the tributary sites. Conversely, it is clear from the temporal assessment that elevated concentrations of aluminum in 2009 and 2010, for example, are due primarily to loading from the tributaries. Without accurate loading information, and using only the average annual values, it is difficult to assess the extent to which the tributaries contribute to elevated constituent concentrations in the Muskeg River. A more rigorous loading assessment is required to assess relative contributions.

The concentrations in Jackpine Creek of carbonaceous oxygen demand, TSS and turbidity as well as those of several metals (Al, Sb, As, Ba, B, Cl, Cr, Co, Cu, Pb, Li, Ni, Mg, Se, Na, Sb, Ti, U, and Va) were particularly high in 2009, indicating a need for more focused monitoring and loading assessment in Jackpine Creek[r1]. With the exception of chlorine, chromium, cobalt, copper, selenium, titanium, turbidity, and vanadium, these constituents are also elevated in Muskeg Creek.

3.2.3 Hydrocarbons

High molecular weight hydrocarbons serve as general indicators of contact with the bitumen ore, and are composed of both aliphatic and aromatic (including PAHs) hydrocarbons. Few historic records of hydrocarbons exist for the Muskeg River basin and of these, only medium weight (C10−C26) hydrocarbons were quantified. There have been relatively few instances of detection of medium weight hydrocarbons (F2: C10−C16) since the inception of the Muskeg River Management Framework, and then only at relatively low concentrations. As well, there is insufficient overlap in the reported carbon number ranges. Consequently, no basis exists for comparison of recent hydrocarbon concentrations with pre-development data. However, the spatial and temporal patterns of hydrocarbon detections provide important insight as to their source in the watershed.

Heavy hydrocarbons exhibit a distinctly seasonal distribution with detections occurring primarily in winter (type 3 pattern), suggesting a seepage-related source. This finding is contrary to the usual assumption that high molecular weight hydrocarbons (PAHs in particular) are not mobile in groundwater. The relative infrequency of hydrocarbon detections during the open water season suggests that erosion and atmospheric deposition are not major sources of hydrocarbon contamination within the Muskeg River watershed. This is not to say these factors are unimportant; detections at all sites in May 2009 indicate they may occasionally contribute to hydrocarbon loading during the open water season. The absence of elevated loading of any parameter indicative either of erosive conditions or an elevated groundwater contribution suggests this May 2009 event may be related to the mobilisation of atmospherically deposited contaminants in the melting snow pack (e.g., Kelly et al. 2009).

Detections of heavy hydrocarbon generally occur throughout the watershed, indicating that a major portion of the hydrocarbon load is associated with natural sources. While hydrocarbon concentrations are usually highest at site M2, the lower portion of the watershed also receives the largest volume of seepage from the McMurray formation, indicated by the phreatic surface of the McMurray aquifer in relation to the ground surface (Hackbarth and Nastasa 1979). As well, hydrocarbon concentrations tend to be higher at site M4.5 (and occasionally at site M6) than at sites M3 and M4, both of which are located downstream and immediately upstream of Syncrude's Aurora settling basin.

Hydrocarbon concentrations at sites M2 and M3, respectively located below and above the Shell Muskeg River Mine settling basin, also do not indicate hydrocarbon loading associated with process water seepage. Whereas hydrocarbon concentrations at site M2 were consistently higher than at site M3 in 2009, the situation was reversed in 2010 and 2011. This may in part reflect the interception of groundwater along the southwestern edge of the Jackpine Mine and compensatory augmentation of discharge in the Muskeg River with Athabasca River water beginning late 2010, although the total volume associated with these activities in the context of the Muskeg River discharge is small. This potential for dilution associated with the compensatory discharge also does

not account for the lower hydrocarbon concentrations observed at site M2 in 2010. On this occasion, the highest hydrocarbon concentrations were observed far upstream at site M4.5. Although the potential for hydrocarbon loading through seepage from the settling basins cannot be excluded, it is clearly of secondary importance relative to the natural hydrocarbon load.

Oil sands naphthenic acids are analytically defined by acid extraction of an acid/base-cleaned aqueous sample followed by quantification against a commercial analytical standard. These acids are also analytically problematic in that they are not strictly naphthenic acids but a complex mixture of carboxylic acids (Grewer et al. 2010). The term "oil sands tailings water acid extractable organics" has been proposed as a more accurate description of this mixture (Fedorak et al. 2010).

The methods by which AENV analyses naphthenic acids were changed twice, first in March 2009 and again in March 2010. The current method, which uses ion trap mass spectrometry, permits characterisation of this mixture according to carbon number and substitution of the C-H bond (z-number). This method may permit more detailed assessment of naphthenic acids in surface water and facilitate source attribution. However, the total naphthenic acid concentration derived by this method is not directly comparable to data analysed prior to March 2010, resulting in an artefactual step in the total naphthenic acid data beginning in March 2010. As well, the composition of the commercial standard used prior to March 2010 results in underestimating the naphthenic acid concentration by a factor of approximately 40%, unless the standard itself is acid extracted. The step changes in the naphthenic acid data preclude direct comparison of pre-March 2009, March 2009−February 2010 and post-March 2010 data and are recorded in the Alberta Environment database by different method codes. These and similar issues associated with the analysis of naphthenic acids are being addressed by a committee of experts from government and academia led by Environment Canada.

As with heavy hydrocarbons, naphthenic acid concentrations are inversely related to flow, indicating a groundwater related source. Naphthenic acid concentrations are fairly constant among sites, although a slight longitudinal gradient is evident with concentrations being highest at site M2. The absence of distinct steps in naphthenic acid concentrations between sites, particularly sites M3 and M4, suggests minimal influence from process-related seepage.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The results presented in this report show that the outcomes of the integrated monitoring program satisfies and meets the limits and targets established under the Management Framework for the Muskeg River. The water quantity was assessed for the water levels of Kearl Lake, flow rates of Muskeg River and water diversions from the Muskeg River watershed. Water quality testing for 2009−2010 was done for a range of parameters, including metals, toxic organic compounds and general chemistry and nutrients. These parameters were measured against a range of criteria specified in the Management Framework to assess compliance with the water quality targets and limits.

For most of 2009 and 2010, water levels of Kearl Lake remained between the established minimum objective and target levels. The goal of the management framework was to maintain natural lake levels fluctuations around the target levels of 331.94 m while remaining above the minimum objectives of 331.71 m. The flows of the Muskeg River also remained well within the green condition for most of 2009−10. A few drops into the red condition were recorded in 2009 and 2010. However, flow rates in both years recovered quickly, reaching green condition within a short period of time. These low flow conditions were most likely in response to relatively low precipitation in the Lower Athabasca Region.

Most water quality parameters were within expected ranges in the Muskeg River through the 2009−10 period. Notable exceptions occurred in 2009 for metals that appear to be related to increased loadings from Jackpine Creek. These impacts appear to be associated either with precipitation events and may be related to the mobilisation of fine particulate matter from cleared areas or from the streambed. Crustal metals such as aluminum are expected to occur at elevated concentrations when there is a high particulate load. Indeed, the mean limit for total aluminum was exceeded in 2009.

There is some question as to whether the current limit for aluminum is excessively stringent. Natural exceedances have been observed prior to development in the basin indicating that replacement of the 100 mg/L mean limit with a site specific objective may be appropriate. Similar guidance is provided in the Lower Athabasca River Water Quality Management Framework. It also appears that current targets, especially those for some metals and polycyclic aromatic hydrocarbons, are excessively stringent and may cause exceedances under natural conditions. This is primarily because the establishment of these targets, which in effect reflect a reference condition approach to impact assessment, was supported by relatively few historic or pre-development data. This is a recurring problem with the reference condition approach, particularly in a setting where development pressure is acute. However, although baseline conditions no longer exist for the monitoring sites an accurate assessment of the appropriateness of existing data for the revision of targets can be conducted based on careful consideration of current trends and point source loading.

The Framework does not have specific provisions for non-development related changes. However, there appears to be a long-term increase in true colour, which also exceeds the limit provided in the framework. It is likely that this change is associated with climate impacts on the export of organic carbon from peatlands and does not have a development related component. It does not appear that the putative climate driver has

produced long-term change in other constituents although covariates of true colour such as arsenic and antimony should be closely monitored.

4.2 RECOMMENDATIONS

Several lessons have been learned over the past three years in implementing the Muskeg River Management Framework. The following recommendations highlight future clarifications, adjustments, revisions and update of the Management Framework:

Water Quantity

- Oil sands mining companies should measure, estimate, or model the withdrawals from surface runoff within the closed circuit areas for each project on at least a monthly, and preferably weekly, basis.

- The surface runoff volumes should be reported separately from the groundwater volumes, which should also be reported on a monthly basis. Oil sands mining companies should continue to report both the withdrawals and returns on a monthly basis, and should also continue to provide an estimate of a closed circuit area on an annual basis. Industry should use the same Alberta Environment-approved method for estimating surface runoff withdrawal for an easier comparison between the projects.

- Due to the current proposed development in the vicinity of Kearl Lake, management actions should be established when the water levels of Kearl Lake rise above the maximum objectives or fall below the minimum objectives.

- Since there are no direct withdrawals from the Muskeg River, restricting withdrawals during low flow periods is challenging. Consideration should be given to flow augmentation systems that could be implemented during low flow periods. It would be expected that since the oil sands mining companies are having a cumulative impact on the flows in the Muskeg River, the mitigation should be shared by the companies as well. Potentially, consideration could be given to the portion of the basin that is being impacted by each project, with credit being given for water that is discharged to the Muskeg River that meets surface water quality guidelines.

Water Quality

- The causes for exceedance of the mean aluminum limit should be investigated, particularly in relation to potential sources within Jackpine Creek. Monitoring currently occurs at a surveillance level and is not designed to attribute source loads. More focused monitoring of Jackpine Creek should be conducted in 2012 in conjunction with the existing monitoring program to identify and quantify particulate and metal loads to Jackpine Creek. Particular attention should be directed at runoff-generating areas and at engineered drainage courses. An additional monitoring site should be established on Jackpine Creek upstream of development. The effectiveness of current and proposed mitigation measures should be assessed.

- Muskeg River Management Framework limits should be aligned with limits adopted for the Lower Athabasca River Water Quality Management Framework.

The mean aluminum limit should be revised accordingly. Targets should also be reviewed against the current data record and revised as appropriate.

- Thorough interpretation of the Muskeg River water quality data is a very time consuming process. This report does not adequately address all the potential drivers of temporal and spatial patterns in the Muskeg River water quality data, and it is likely that some of the patterns and drivers are neglected. In future, a more detailed water quality analysis should be conducted separately from the annual reporting carried out under the Muskeg River Management Framework.
- Future Muskeg River Management Framework reports should assess mass loadings of constituents from point sources such as tributaries (in particular, T3.1 and T5) and discharge points. This necessitates timely access to discharge volume and water quality data collected under EPEA operating approvals for annual reporting purposes. An appropriate database and a rigorous data management structure are essential.
- The volume of Stanley Creek is enhanced by the diversion of water around the Syncrude Aurora mine. Loadings from Stanley Creek should be accounted for in the monitoring program, either by inclusion of Stanley Creek in the monitoring program or by more effective reporting of data collected under regulatory approvals.
- The naphthenic acid profile data, analysed since March 2010, should be assessed in detail to determine whether distinct source signatures exist within the watershed.
- An additional site should be established upstream of site M6 to capture potential influence from the Imperial Kearl oil sands project

REFERENCES

Alberta Environment. 2008. Muskeg River Interim Management Framework for Water Quantity and Quality, Alberta Environment, 99 pp.

Bauer, M and C. Blodau. 2006. Mobilization of arsenic by dissolved organic matter from iron oxides, soils and sediments. Science of the Total Environment. 354 (2-3), 179-190.

Hackbarth, D.A. and N. Nastasa. 1979. The hydrogeology of the Athabasca Oil Sands area, Alberta. Alberta Research Council Bulletin 38. 39 pp.

Kelly, E.N., J.W. Short, D.W. Schindler, P.V. Hodson, M. Ma, A.K. Kwan and B.L. Fortin. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences USA 106: 22346-22351.

Fedorak, P.M., D.M. Grewer, R.F. Young and R.M. Whittal. 2010. Are "naphthenic acids" from oil sands tailings waters really naphthenic acids? *in:* Proceedings of the Second International Oil Sands Tailings Conference, pp. 197-203.

Grewer, D.M., R.F. Young, R.M. Whittal and P.M. Fedorak. 2010. Naphthenic acids and other acid-extractables in water samples from Alberta: what is being measured? Science of the Total Environment 408(23):5997-6010.

Regional Aquatic Monitoring Program (RAMP). 2011. Regional Aquatic Monitoring Program 2010 technical report. Prepared by Hatfield Consultants. West Vancouver, British Columbia.

van den Heuvel, M.R., M. Power, M.D. MacKinnon, T. Van Meer, E.P. Dobson, and D.G. Dixon. 1999. Effects of oil sands related aquatic reclamation on yellow perch (Perca flavescens). I. Water quality characteristics and yellow perch physiological and population responses. Canadian Journal of Fisheries and Aquatic Sciences. 56: 1213-1225.

APPENDIX 1. WATER QUALITY TARGETS AND LIMITS FOR THE MUSKEG RIVER

Water Quality Parameter	Units	Measured Mean	WQT Mean Target (Yellow)	Measured Peak/Max	WQT Peak Target (Yellow)	WQL Mean Limit (Red)	WQL Peak Limit (Red)
General Chemistry and Nutrients							
Chlorophyll a	mg/m^3	0.9	5	2.8	12	NA	NA
Total Kjeldahl Nitrogen	mg/L	0.9	1.3	1.2	3.5	RSWQO	NA
Nitrate + Nitrite	µg/L	**42**	30 (70)	87	362 (1.024)	RSWQO	29000
Ammonia	µg/L	**188**	179 (234)	560	718 (1.28)	500	2400
Total Phosphorus	µg/L	39	42	99	219	50 (RSWQO)	NA
Dissolved Organic Carbon	mg/L	21.4	25.6	27.8	63.1	NA	NA
True Colour	TCU	**89**	63 (77)	**137**	115 (198)	NA	NA
Total Alkalinity ($CaCO_3$)	mg/L	192	225	301	398	NA	NA
Chloride	mg/L	3.7	5.4	13.6	34.1	230	250
Sulphate	mg/L	6.4	11.4	8.0	106.5	500	500
Conductivity	µS/cm	364	418	578	799	NA	NA
pH	pH units	7.5	6.5, 9.2	7.9	6.0, 10.8	6.5	RSWQO
Biochemical Oxygen Demand	mg/L	**1.4**	1.4 (1.64)	**3.4**	2.4 (4.3)	Based on DO	
Dissolved Oxygen	mg/L	8.13	>6.5*	1.5^m	1.44^m	6.5*	5*
Total Suspended Solids	mg/L	5	6.5	16	82.2	NA	NA
Turbidity	NTU	6.4	9	17.2	77	NA	NA
Metals							
Aluminum (total)	µg/L	**114**	61 (62)	**540**	162 (253)	ASWQG	RSWQO

						variable	
Arsenic (total)	µg/L	0.3	0.4	0.5	0.9	RSWQO	0.005
Boron (total)	µg/L	45	50	62	70	55	200
Barium (total)	µg/L	42	84	73	138	88 (RSWQO)	NG
Cadmium (total)	µg/L	0.007	0.019	0.04	0.2	ASWQG variable	1.1
Chromium (total)	µg/L	0.3	0.7	0.6	3.4	8	8.3
Copper (total)	µg/L	0.3	0.5	0.5	0.8	7	170
Iron (total)	mg/L	1.020	1.0218	1.860	2.6364	NG	RSWQO
Mercury (total)	ng/L	1.54	ID	2.98	ID	5	13
Lithium (total)	µg/L	9.7	11.9	14.3	15.4	NG	NG
Manganese (total)	mg/L	0.1800	0.2359	0.7630	1.2732	0.39	RSWQO
Molybdenum (total)	µg/L	0.1	0.2	0.3	0.3	28	730
Nickel (total)	µg/L	0.4	0.6	1	1.3	7.2	62
Lead (total)	µg/L	0.066	0.1	**0.230**	0.1	1	2
Selenium (total)	µg/L	0.1	ID	0.3	0.7	RSWQO	1
Strontium (total)	mg/L	0.125	0.224	0.216	0.260	3.3 (RSWQO)	NG
Vanadium (total)	µg/L	**0.5**	0.4	**1.26**	0.6	17	160
Zinc (total)	µg/L	1.4	4	3.5	13	RSWQO	30
Organics							
Acenaphthylene	µg/L	100%<MDL	80% <MDL	-	0.042	NA	5.8
Benzo(a)anthracene	µg/L	100%<MDL	80% <MDL	-	0.0036	NA	0.018
Benzo(b,j,k)fluoranthene	µg/L	92%<MDL	80% <MDL	**0.015**	0.0108	NA	NG
Benzo(g,h,i)perylene	µg/L	92%<MDL	80% <MDL	**0.009**	0.0024	NA	0.0152
Chrysene	µg/L	100%<MDL	80% <MDL	-	0.0048	NA	NG
Dibenz(a,h)anthracene	µg/L	100%<MDL	80% <MDL	-	ID	NA	NG
Fluoranthene	µg/L	100%<MD	80% <MDL	-	0.0048	NA	0.04

		L					
Fluorene	µg/L	100%<MDL	80% <MDL	-	0.0192	NA	3
Indeno(1,2,3-c,d)pyrene	µg/L	92%<MDL	80% <MDL	**0.007**	0.0048	NA	NG
Napthalene	µg/L	100%<MDL	80% <MDL	-	1.068	NA	1.1
Phenanthrene	µg/L	92%<MDL	80% <MDL	0.007	0.0144	NA	0.4
Pyrene	µg/L	100%<MDL	80% <MDL	-	0.0048	NA	0.025

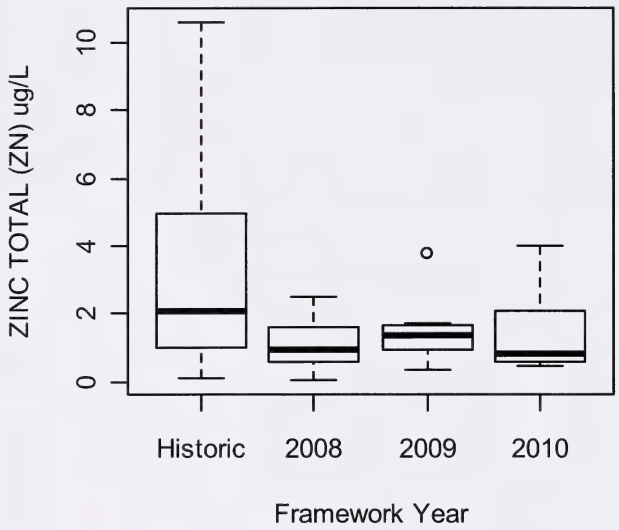
* During open water periods only, m = minimum WQT for entire year recognizing that this occurs only in winter
ASWQG = Alberta Surface Water Quality Guidelines (Alberta Environment 1999).
RSWQO = Reach Specific Water Quality Objective development required
80% <MDL = 80% of values are below the Method Detection Limit
NA = Not Applicable
ID = Insufficient Data
NG = No Guideline, candidate for RSWQO
See Appendix A for more details.

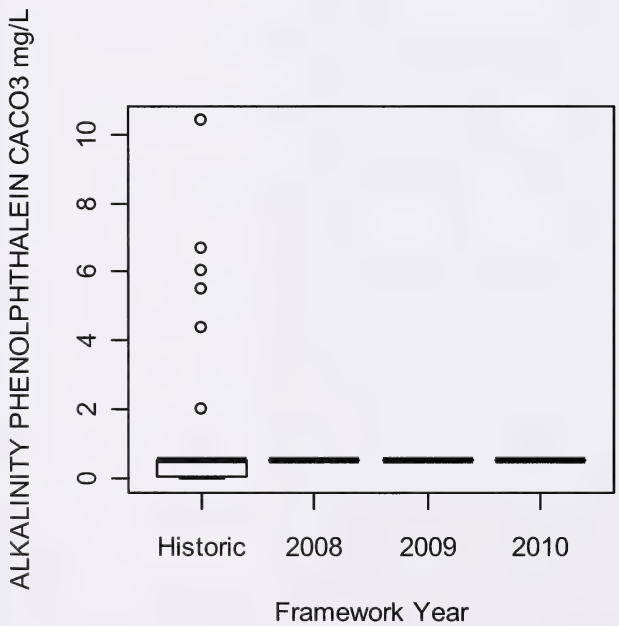
APPENDIX 2. ACRONYMS AND ABBREVIATIONS

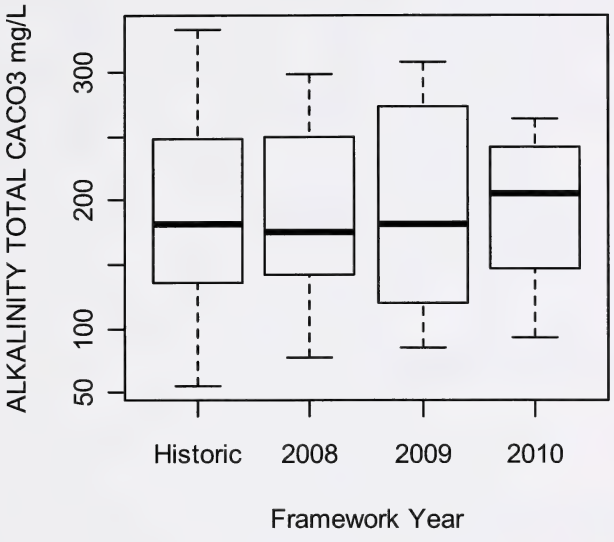
AENV	Alberta Environment
AEP	Alberta Environmental Protection
ASRD	Alberta Sustainable Resource Development
ASWQG	Alberta Surface Water Quality Guideline
ATC	Athabasca Tribal Council
BOD	biochemical oxygen demand
$CaCO_3$	calcium carbonate
CCME	Canadian Council of Ministers of the Environment
CEMA	Cumulative Environmental Management Association
M^3/S	cubic metres per second
DO	dissolved oxygen
DOC	dissolved organic carbon
DFO	Fisheries and Oceans Canada
EIA	Environmental Impact Assessment
EPEA	*Environmental Protection and Enhancement Act*
ERCB	Energy Resources Conservation Board
EUB	Energy and Utilities Board
FN	First Nation
GIS	Geographic Information System
HSPF	Hydrologic Simulation Program - Fortran
IFN	Instream Flow Needs
IRC	Industry Relations Corporation
km^2	square kilometre
m	metre
masl	metres above sea level
m/km	metres per kilometre
m^3/s	cubic metres per second
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre
mm	millimetre
µg/L	micrograms per litre
µS/cm	microSiemens per centimetre
ng/L	nanograms per litre
NTU	Nephelometric turbidity units

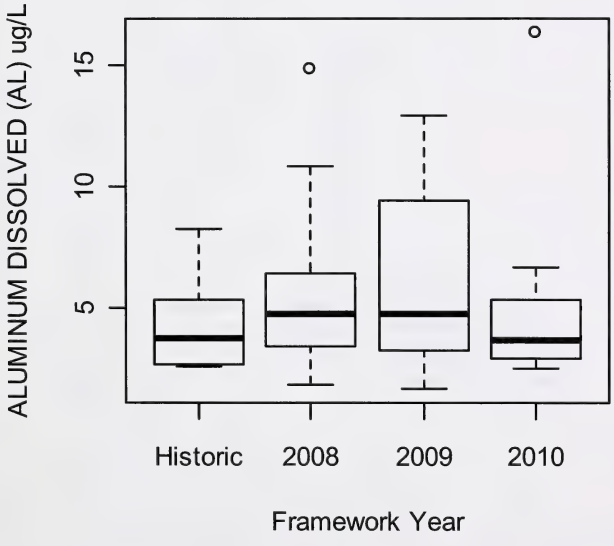
RAMP	Regional Aquatics Monitoring Program
RSDS	Regional Sustainable Development Strategy
RSWQO	Reach Specific Water Quality Objective
SPAR	Suggest, Propose, Advise and Recommend
TDS	total dissolved solids
TEK	Traditional Ecological Knowledge
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TSS	total suspended solids
U.S. EPA	United States Environmental Protection Agency
WITG	Watershed Integrity Task Group
WQL	Water Quality Limit
WQT	Water Quality Target

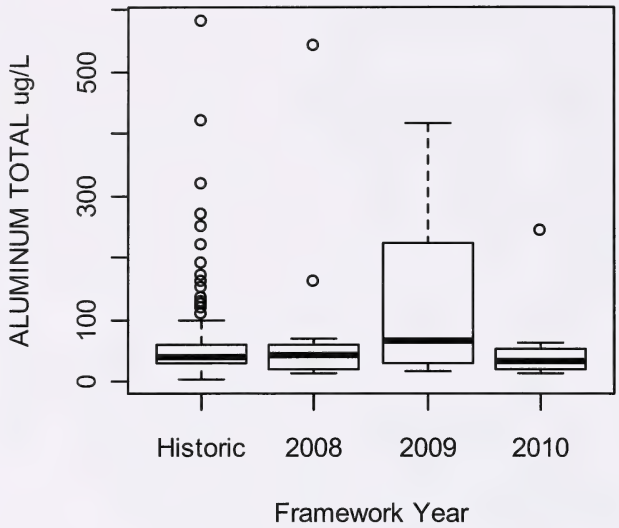
APPENDIX 3. TEMPORAL COMPARISON OF CONSTITUENT CONCENTRATIONS FOR 2009 AND 2010 AT SITE M2

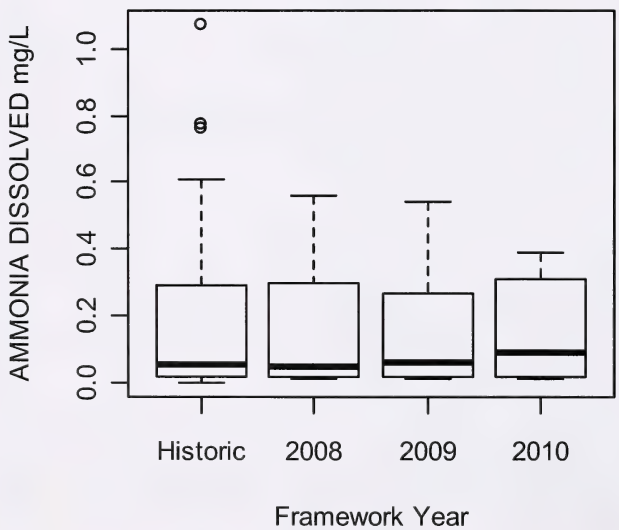


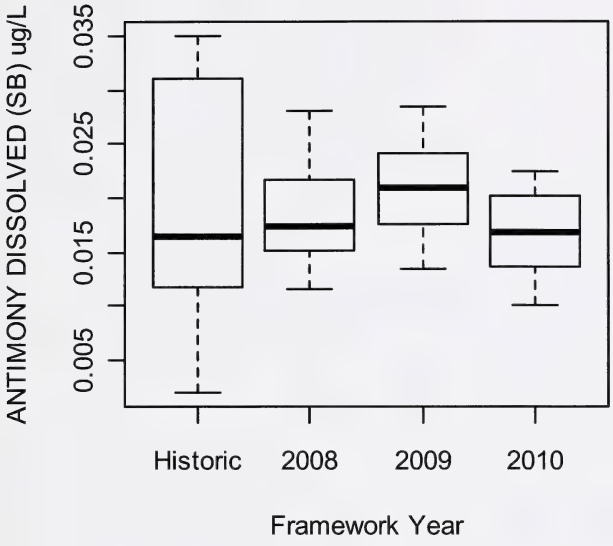


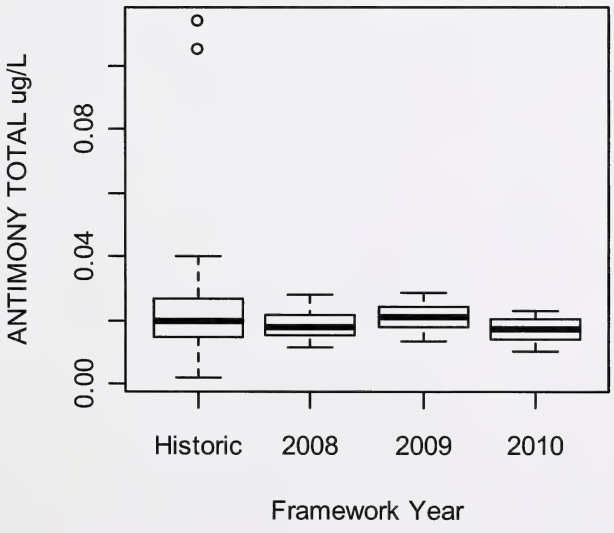

ALKALINITY TOTAL CACO3 mg/L
50
100
200
300
Historic
2008
2009
2010
Framework Year

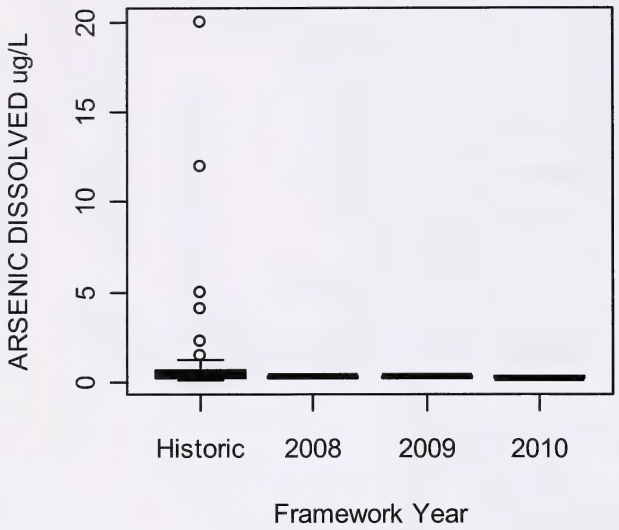

ALUMINUM DISSOLVED (AL) ug/L
5
10
15
Historic
2008
2009
2010
Framework Year

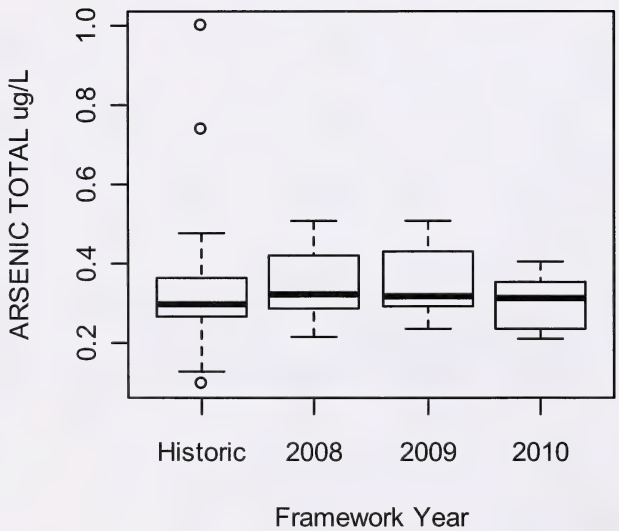

ALUMINUM TOTAL ug/L
0
100
300
500
Historic
2008
2009
2010
Framework Year

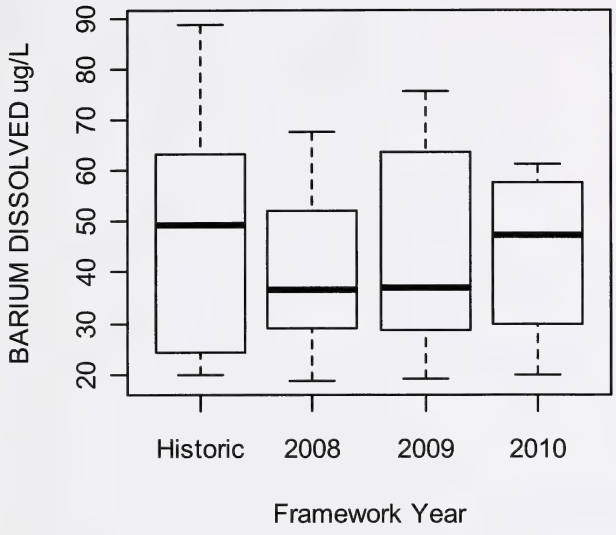

AMMONIA DISSOLVED mg/L
0.0
0.2
0.4
0.6
0.8
1.0
Historic
2008
2009
2010
Framework Year

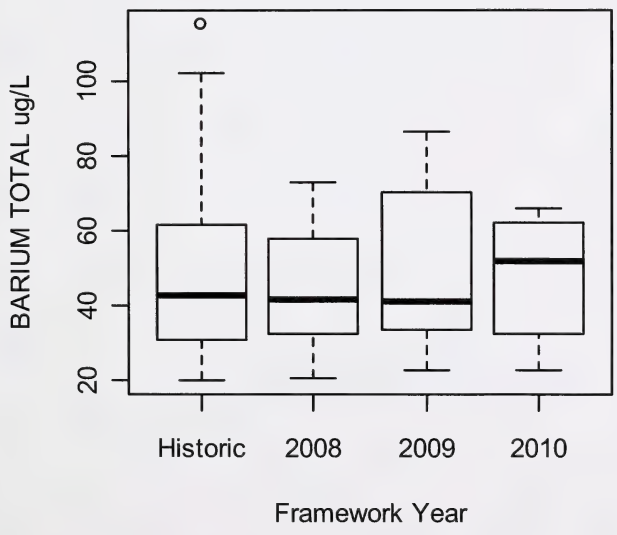

ANTIMONY DISSOLVED (SB) ug/L
0.005
0.015
0.025
0.035
Historic
2008
2009
2010
Framework Year

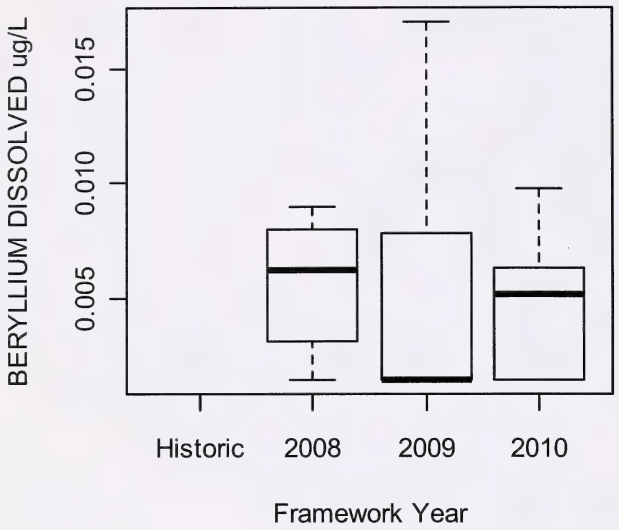

ANTIMONY TOTAL ug/L
0.00
0.04
0.08
Historic
2008
2009
2010
Framework Year

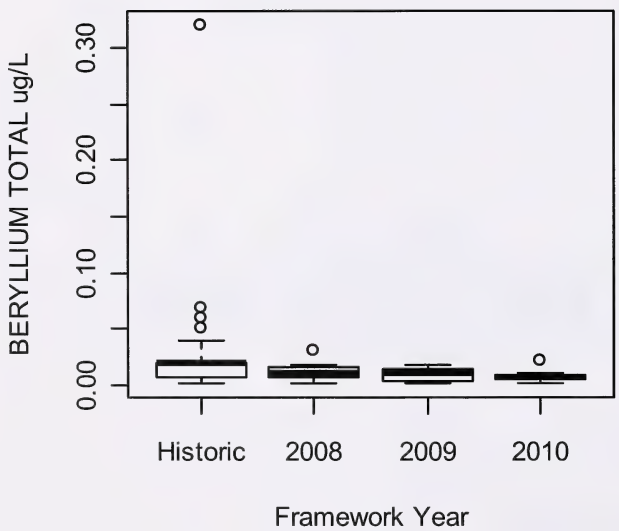

ARSENIC DISSOLVED ug/L
0
5
10
15
20
Historic
2008
2009
2010
Framework Year

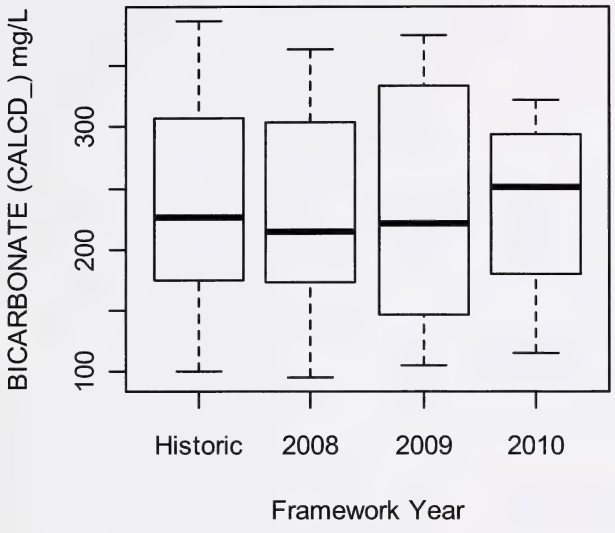

ARSENIC TOTAL ug/L
0.2
0.4
0.6
0.8
1.0
Historic
2008
2009
2010
Framework Year

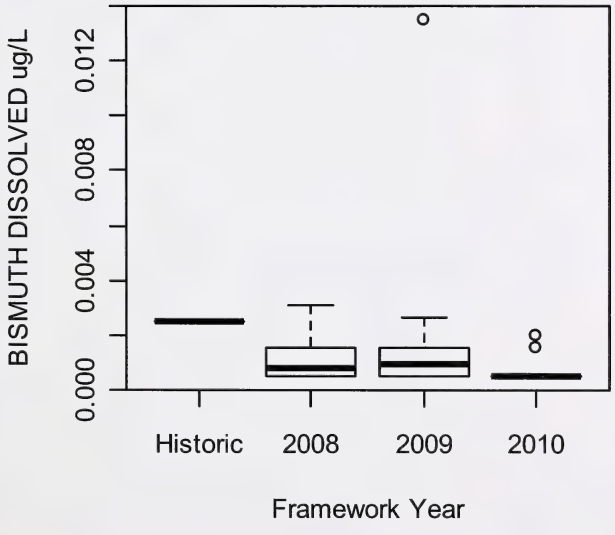

BARIUM DISSOLVED ug/L
20
30
40
50
60
70
80
90
Historic
2008
2009
2010
Framework Year

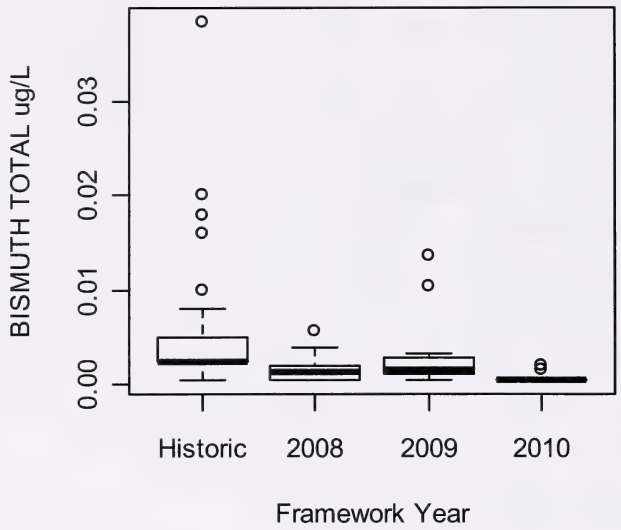

BARIUM TOTAL ug/L
20
40
60
80
100
Historic
2008
2009
2010
Framework Year

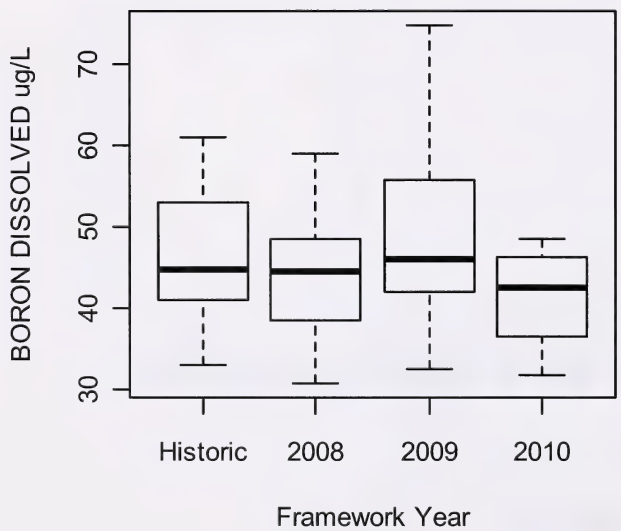

BERYLLIUM DISSOLVED ug/L
0.005
0.010
0.015
Historic
2008
2009
2010
Framework Year

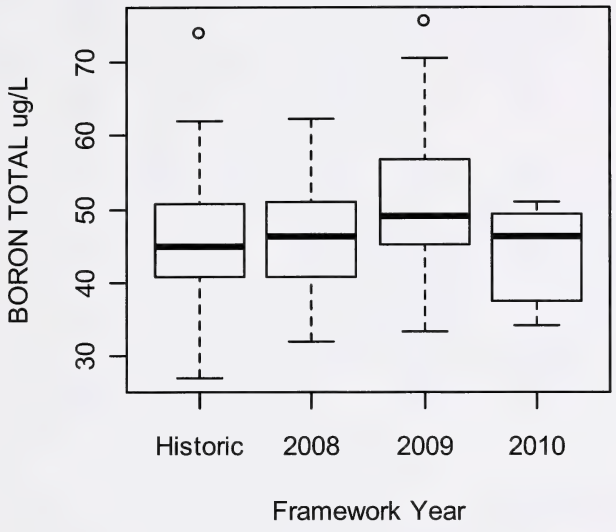

BERYLLIUM TOTAL ug/L
0.00
0.10
0.20
0.30
Historic
2008
2009
2010
Framework Year

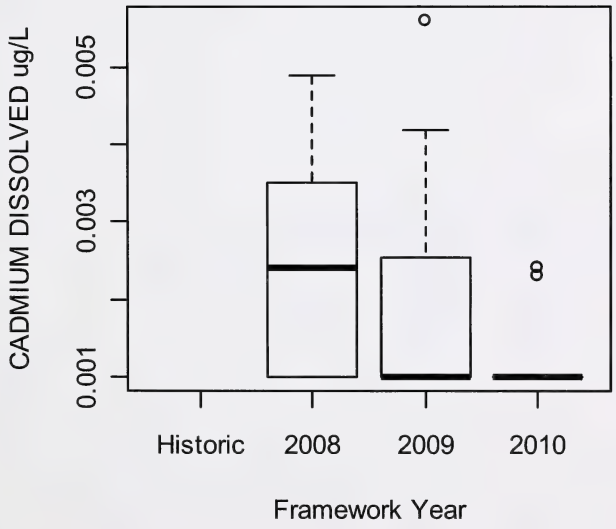

BICARBONATE (CALCD_) mg/L
100
200
300
Historic
2008
2009
2010
Framework Year

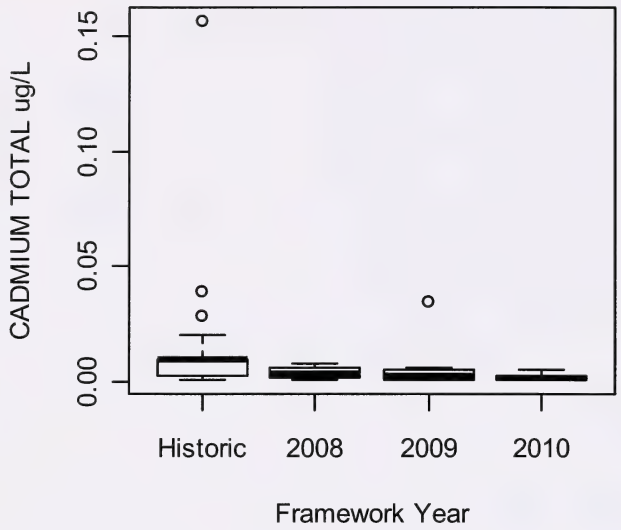

BISMUTH DISSOLVED ug/L
0.000
0.004
0.008
0.012
Historic
2008
2009
2010
Framework Year

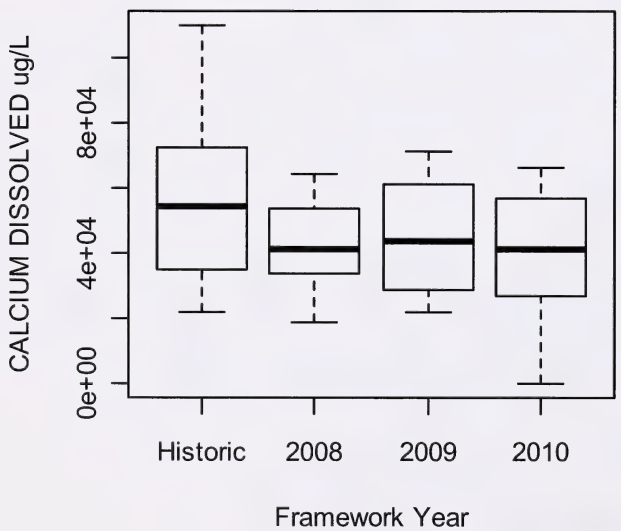

BISMUTH TOTAL ug/L
0.00
0.01
0.02
0.03
Historic
2008
2009
2010
Framework Year

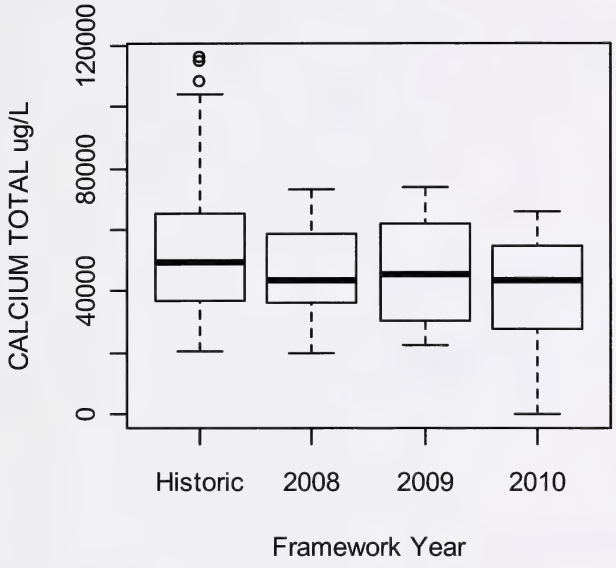

BORON DISSOLVED ug/L
30
40
50
60
70
Historic
2008
2009
2010
Framework Year

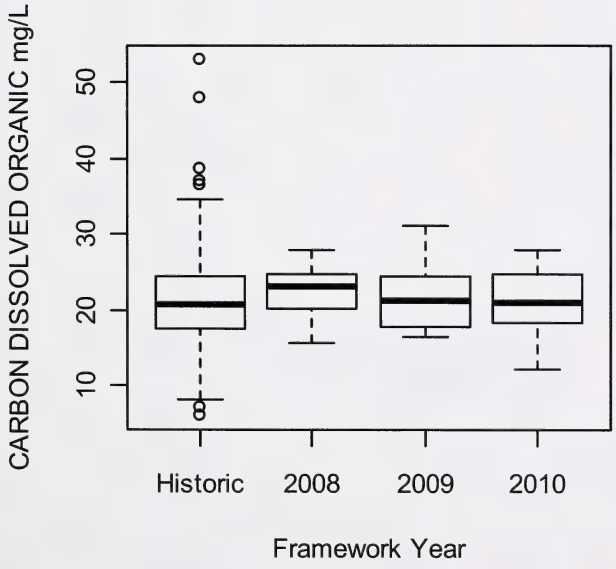

BORON TOTAL ug/L
30
40
50
60
70
Historic
2008
2009
2010
Framework Year

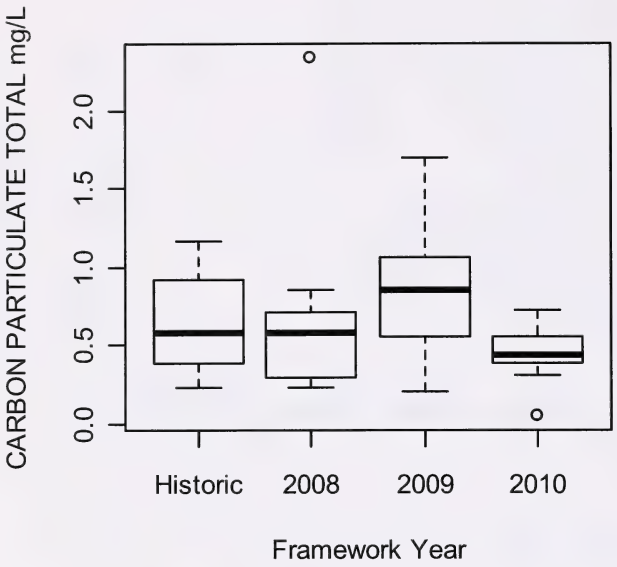

CADMIUM DISSOLVED ug/L
0.001
0.003
0.005
8
Historic
2008
2009
2010
Framework Year

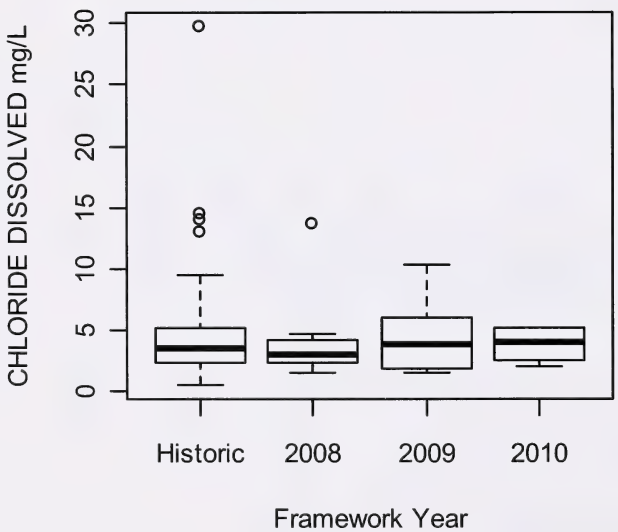

CADMIUM TOTAL ug/L
0.00
0.05
0.10
0.15
Historic
2008
2009
2010
Framework Year

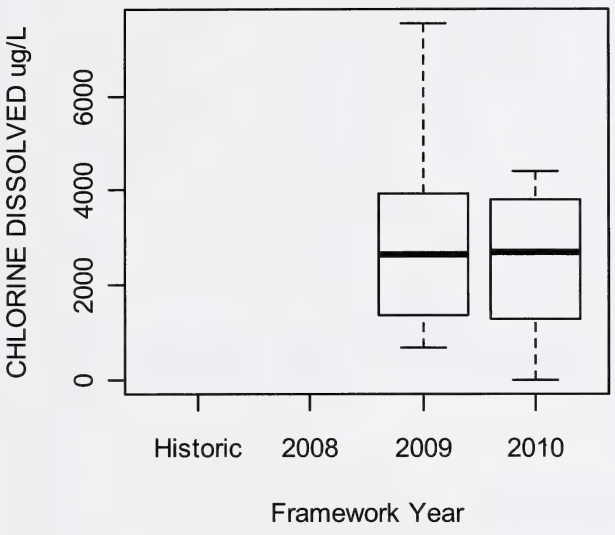

CALCIUM DISSOLVED ug/L
0e+00
4e+04
8e+04
Historic
2008
2009
2010
Framework Year

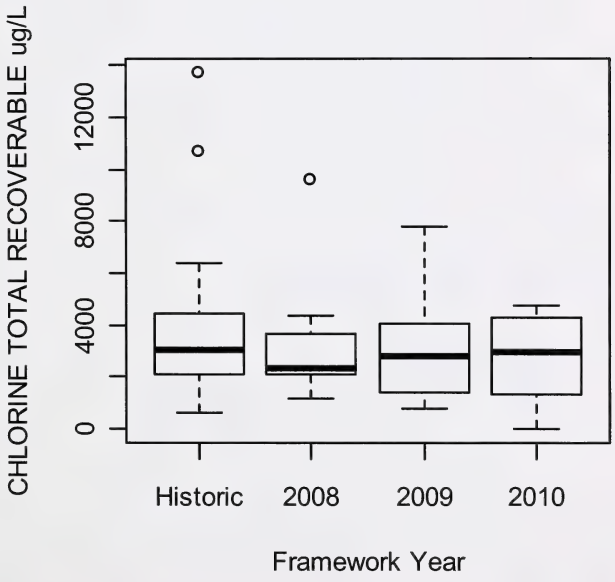

CALCIUM TOTAL ug/L
0
40000
80000
120000
Historic
2008
2009
2010
Framework Year

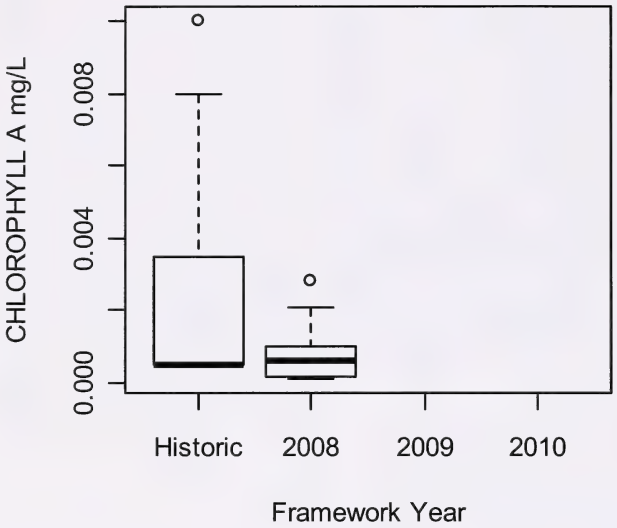

CARBON DISSOLVED ORGANIC mg/L
10
20
30
40
50
Historic
2008
2009
2010
Framework Year

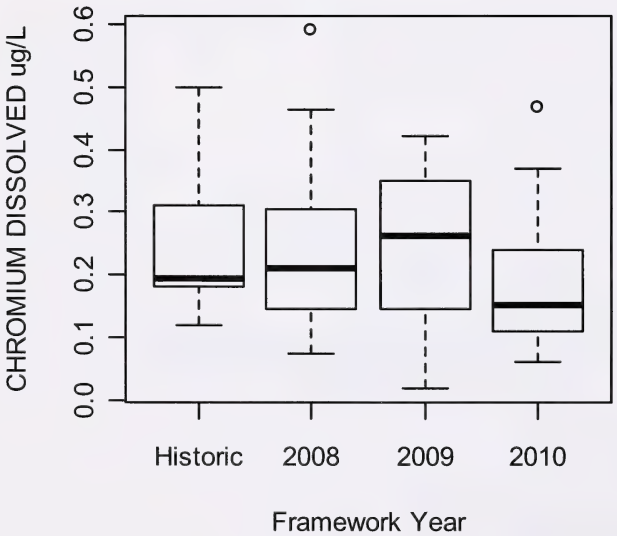

CARBON PARTICULATE TOTAL mg/L
0.0
0.5
1.0
1.5
2.0
Historic
2008
2009
2010
Framework Year

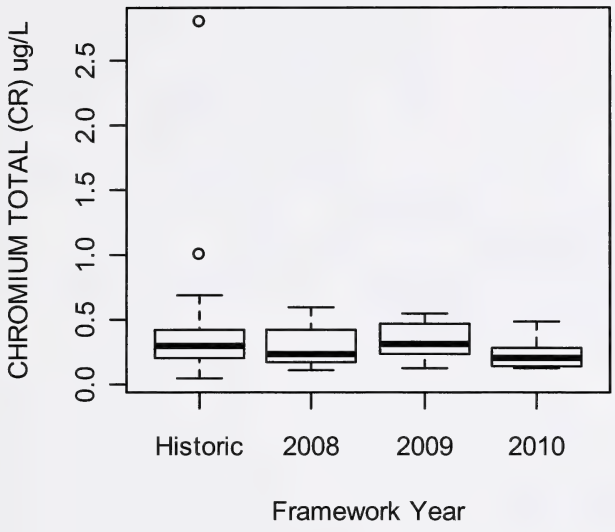

CHLORIDE DISSOLVED mg/L
0
5
10
15
20
25
30
Historic
2008
2009
2010
Framework Year

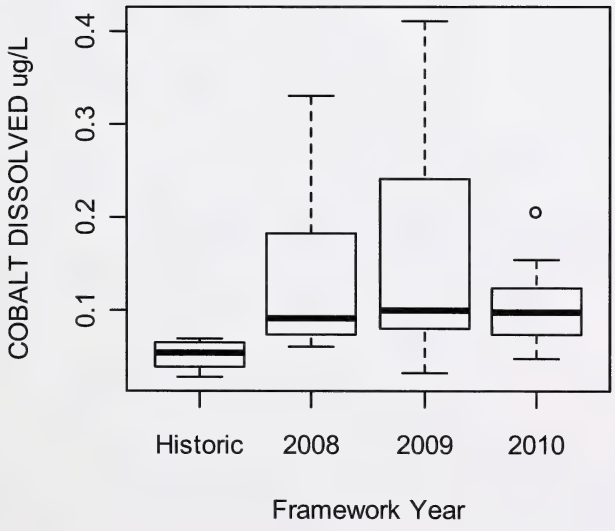

CHLORINE DISSOLVED ug/L
0
2000
4000
6000
Historic
2008
2009
2010
Framework Year

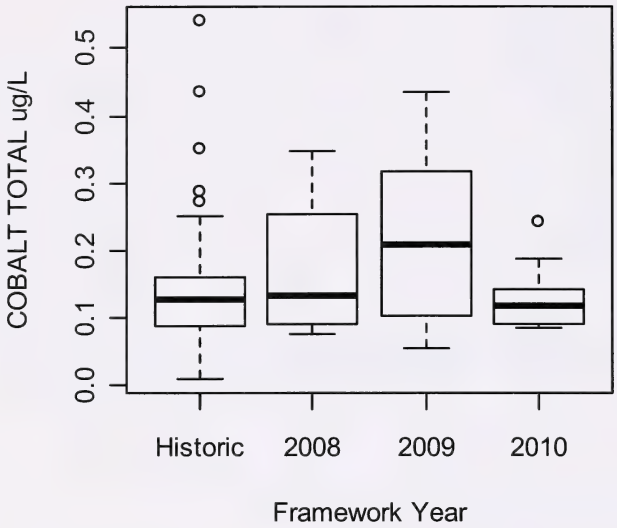

CHLORINE TOTAL RECOVERABLE ug/L
0
4000
8000
12000
Historic
2008
2009
2010
Framework Year

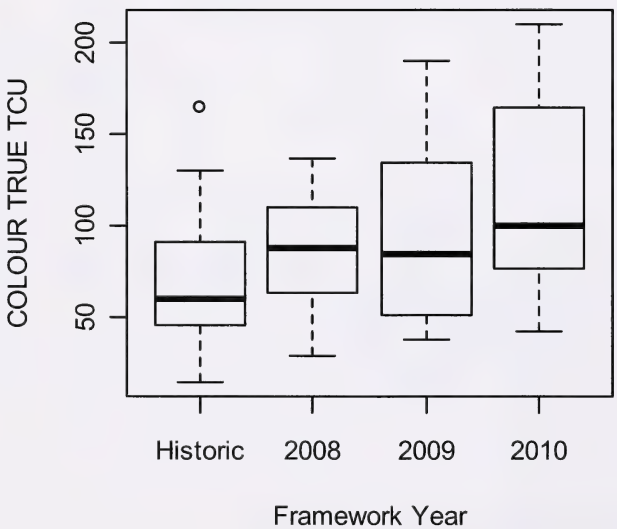

CHLOROPHYLL A mg/L
0.000
0.004
0.008
Historic
2008
2009
2010
Framework Year

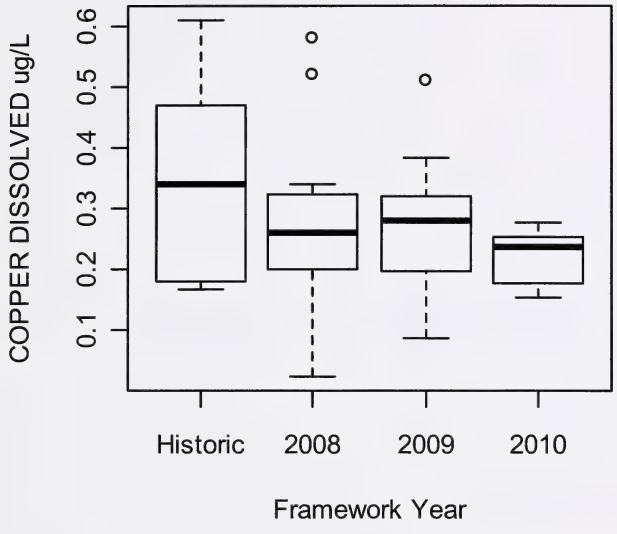

CHROMIUM DISSOLVED ug/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Historic
2008
2009
2010
Framework Year

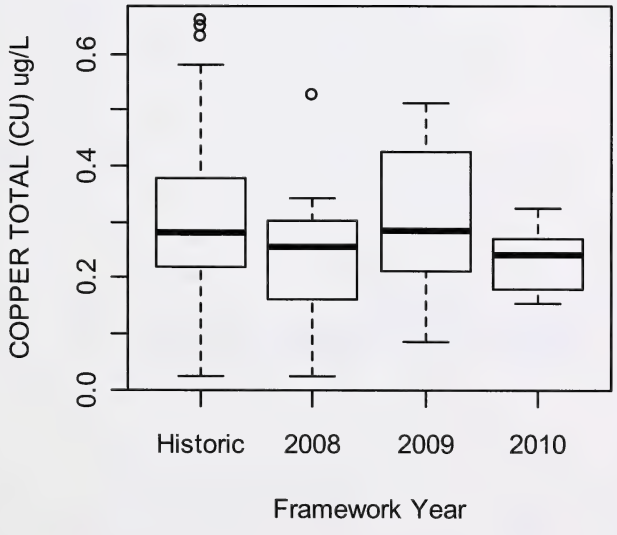

CHROMIUM TOTAL (CR) ug/L
0.0
0.5
1.0
1.5
2.0
2.5
Historic
2008
2009
2010
Framework Year

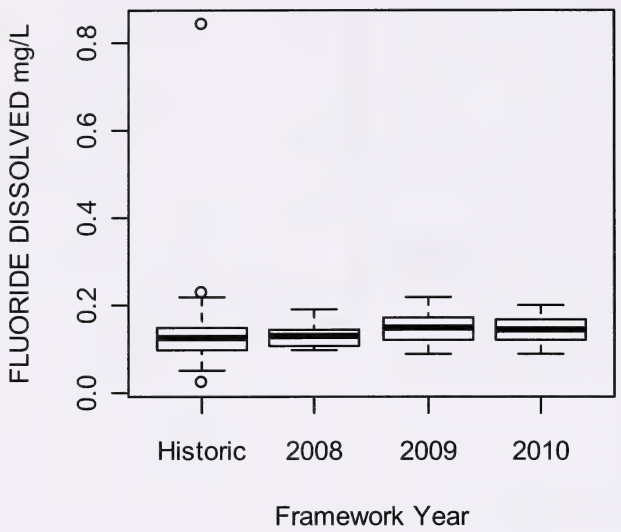

COBALT DISSOLVED ug/L
0.1
0.2
0.3
0.4
Historic
2008
2009
2010
Framework Year

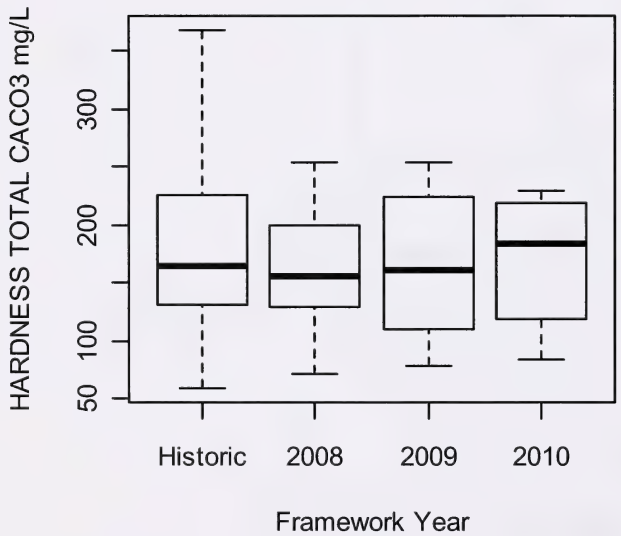

COBALT TOTAL ug/L
0.0
0.1
0.2
0.3
0.4
0.5
Historic
2008
2009
2010
Framework Year

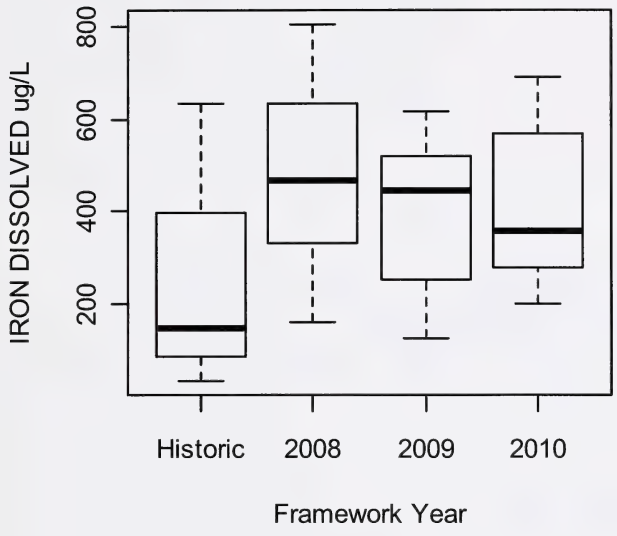

COLOUR TRUE TCU
50
100
150
200
Historic
2008
2009
2010
Framework Year

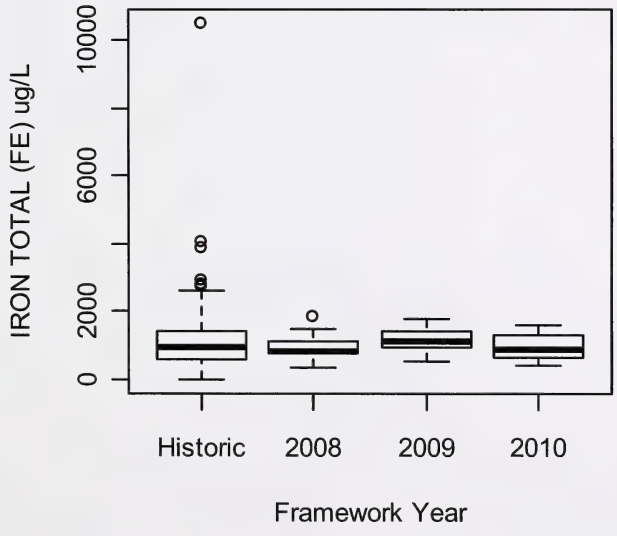

COPPER DISSOLVED ug/L
0.1
0.2
0.3
0.4
0.5
0.6
Historic
2008
2009
2010
Framework Year

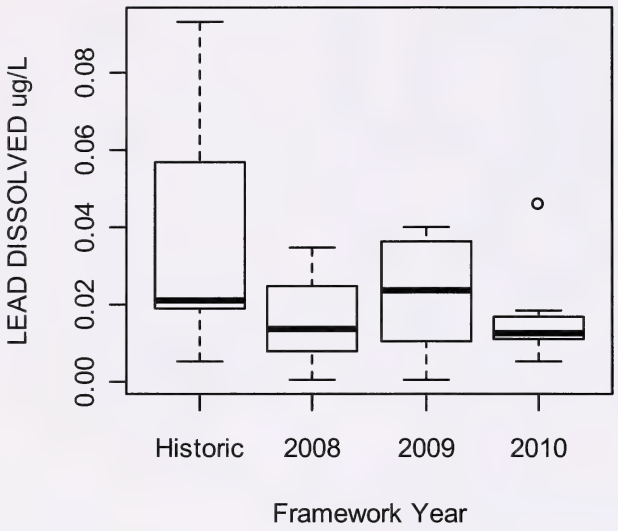

COPPER TOTAL (CU) ug/L
0.0
0.2
0.4
0.6
Historic
2008
2009
2010
Framework Year

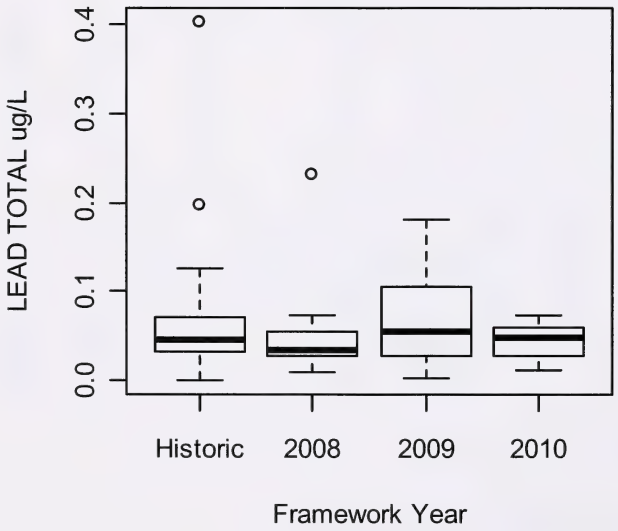

FLUORIDE DISSOLVED mg/L
0.0
0.2
0.4
0.6
0.8
Historic
2008
2009
2010
Framework Year

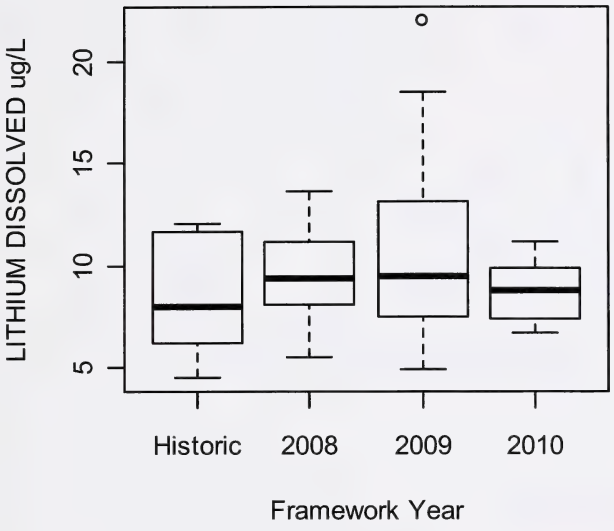

HARDNESS TOTAL CACO3 mg/L
50
100
200
300
Historic
2008
2009
2010
Framework Year

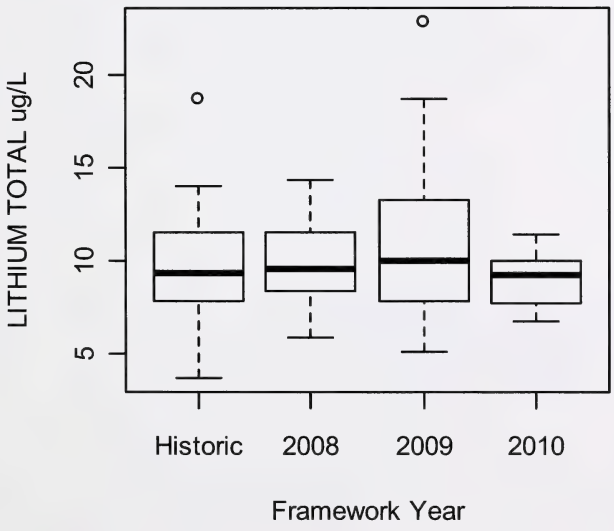

IRON DISSOLVED ug/L
200
400
600
800
Historic
2008
2009
2010
Framework Year

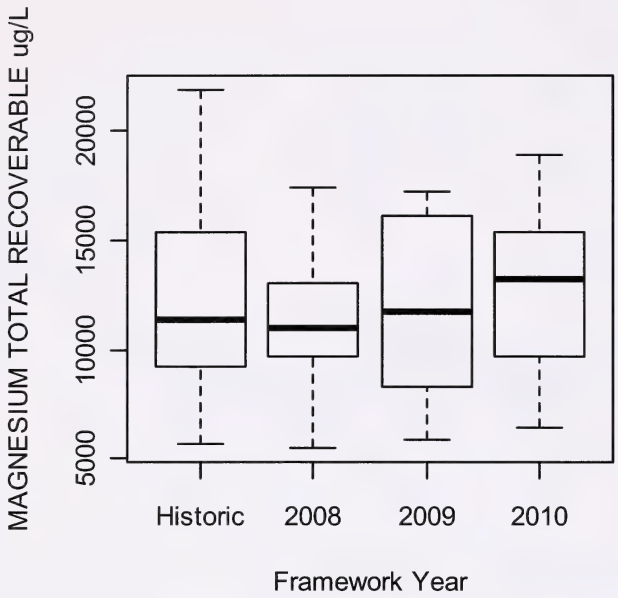

IRON TOTAL (FE) ug/L
0
2000
6000
10000
Historic
2008
2009
2010
Framework Year

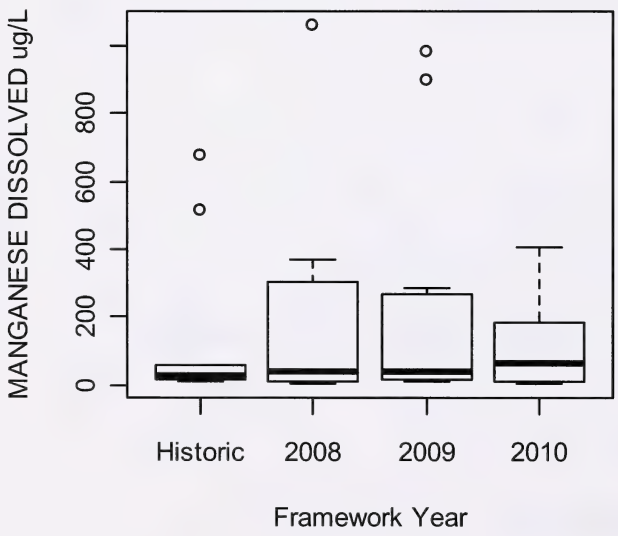

LEAD DISSOLVED ug/L
0.00
0.02
0.04
0.06
0.08
Historic
2008
2009
2010
Framework Year

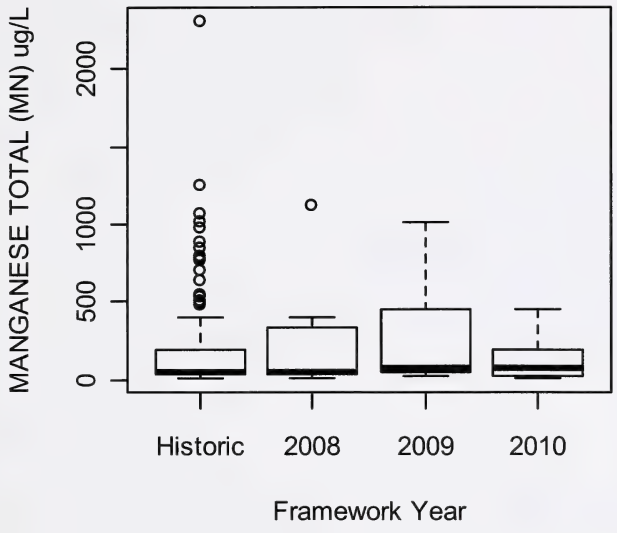

LEAD TOTAL ug/L
0.0
0.1
0.2
0.3
0.4
Historic
2008
2009
2010
Framework Year

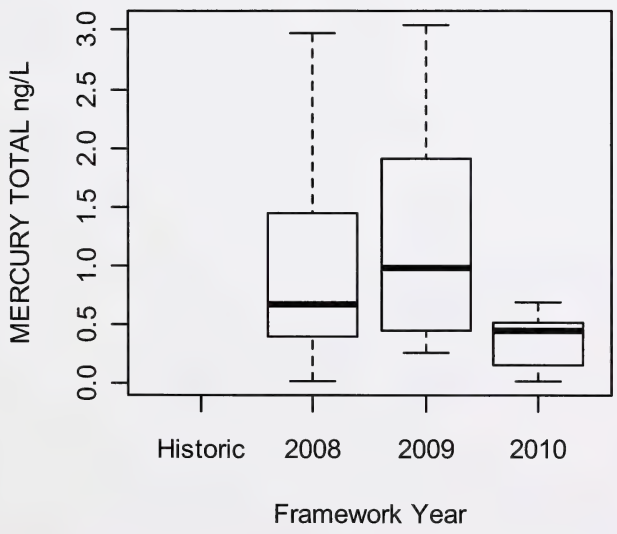

LITHIUM DISSOLVED ug/L
5
10
15
20
Historic
2008
2009
2010
Framework Year

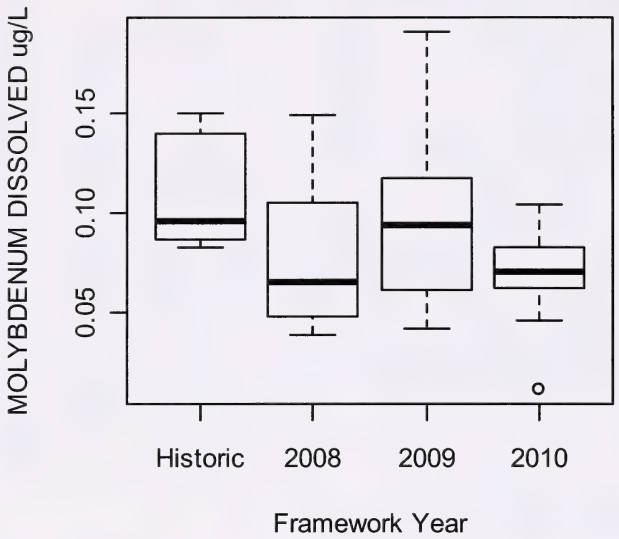

LITHIUM TOTAL ug/L
5
10
15
20
Historic
2008
2009
2010
Framework Year

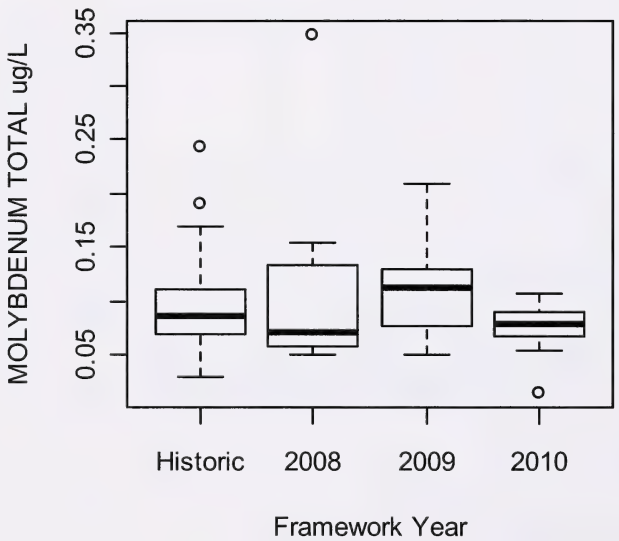

MAGNESIUM TOTAL RECOVERABLE ug/L
5000
10000
15000
20000
Historic
2008
2009
2010
Framework Year

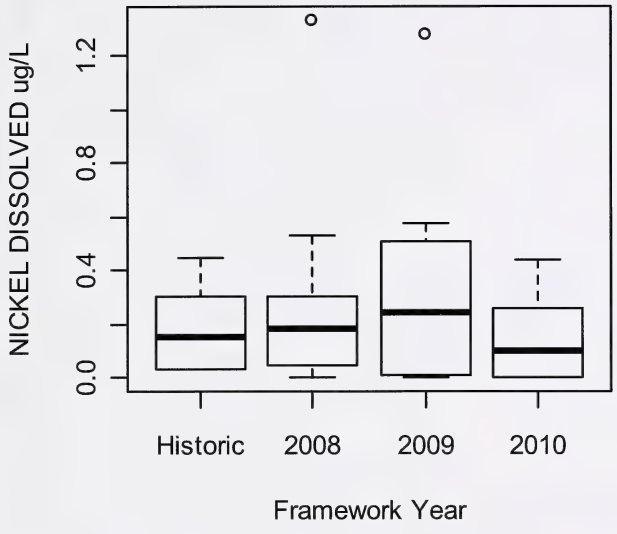

MANGANESE DISSOLVED ug/L
0
200
400
600
800
Historic
2008
2009
2010
Framework Year

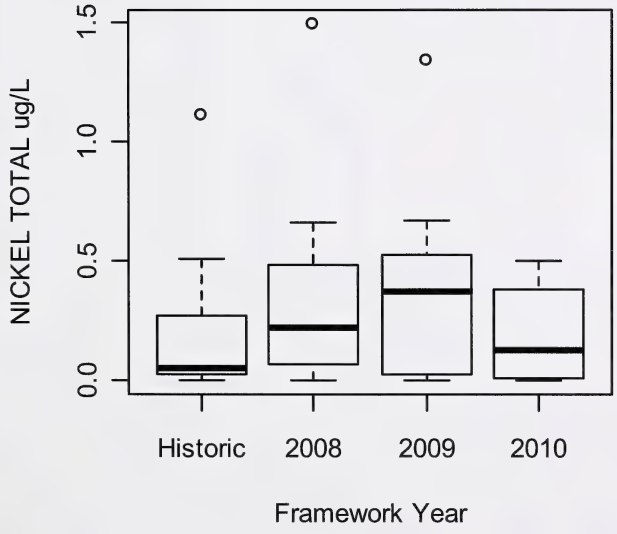

MANGANESE TOTAL (MN) ug/L
0
500
1000
2000
Historic
2008
2009
2010
Framework Year

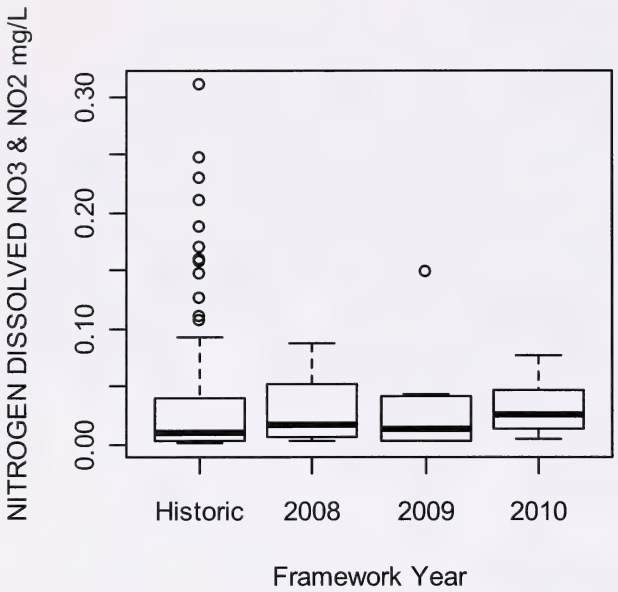

MERCURY TOTAL ng/L
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Historic
2008
2009
2010
Framework Year

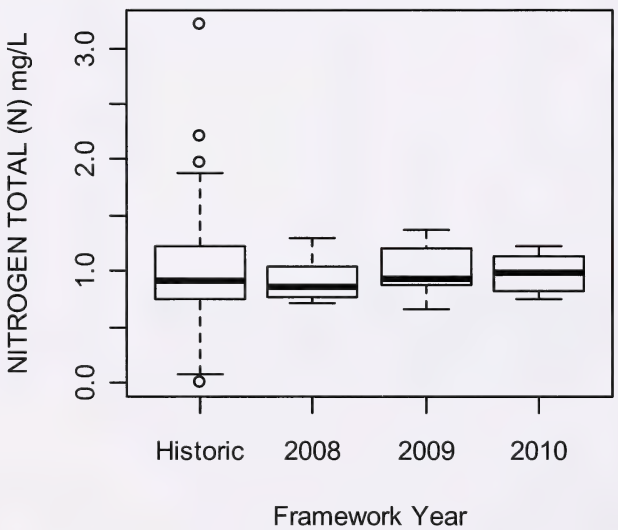

MOLYBDENUM DISSOLVED ug/L
0.05
0.10
0.15
Historic
2008
2009
2010
Framework Year

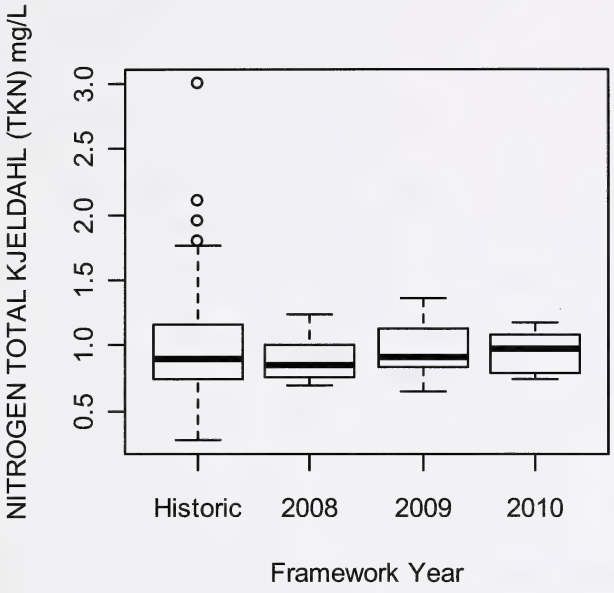

MOLYBDENUM TOTAL ug/L
0.05
0.15
0.25
0.35
Historic
2008
2009
2010
Framework Year

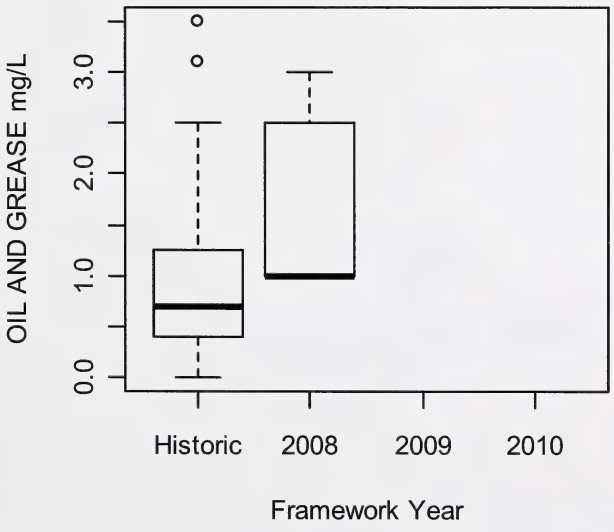

NICKEL DISSOLVED ug/L
0.0
0.4
0.8
1.2
Historic
2008
2009
2010
Framework Year

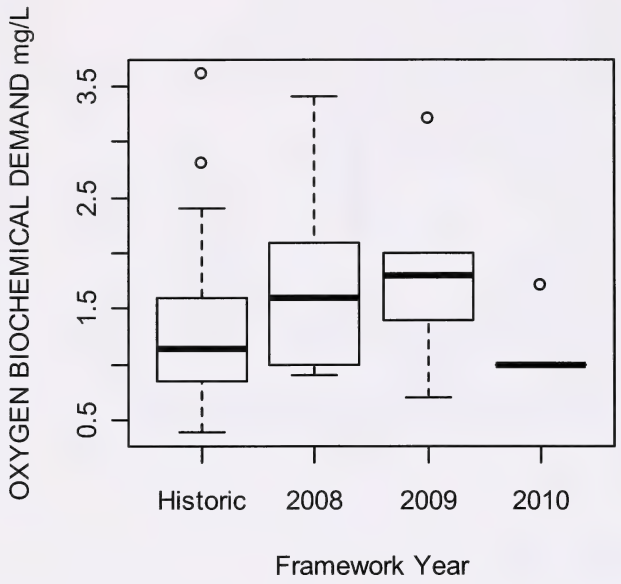

NICKEL TOTAL ug/L
0.0
0.5
1.0
1.5
Historic
2008
2009
2010
Framework Year

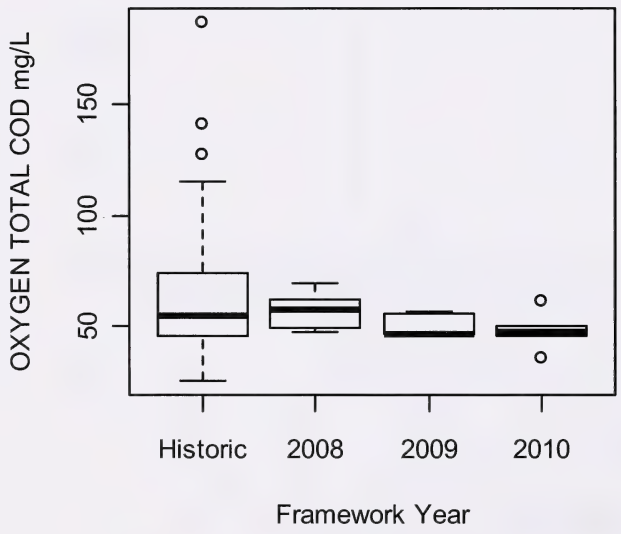

NITROGEN DISSOLVED NO3 & NO2 mg/L
0.00
0.10
0.20
0.30
Historic
2008
2009
2010
Framework Year

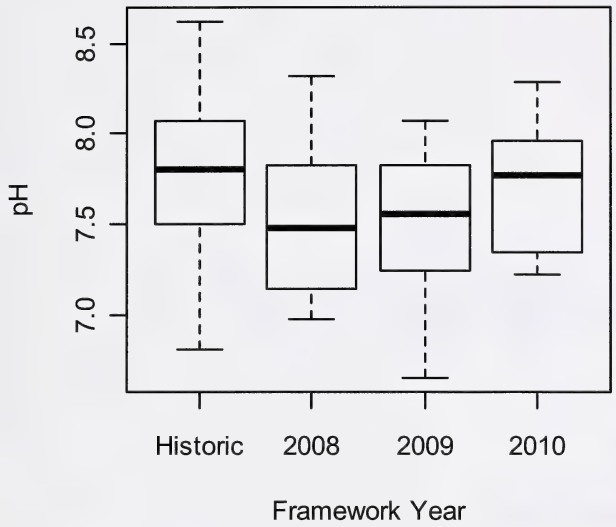

NITROGEN TOTAL (N) mg/L
0.0
1.0
2.0
3.0
Historic
2008
2009
2010
Framework Year

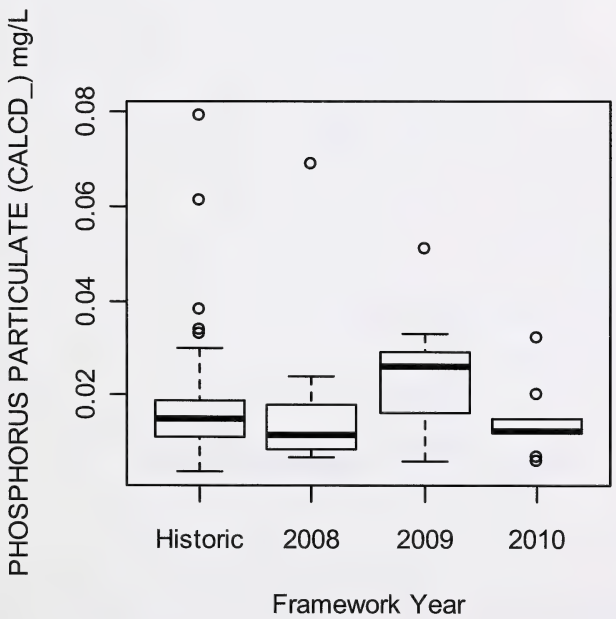

NITROGEN TOTAL KJELDAHL (TKN) mg/L
0.5
1.0
1.5
2.0
2.5
3.0
Historic
2008
2009
2010
Framework Year

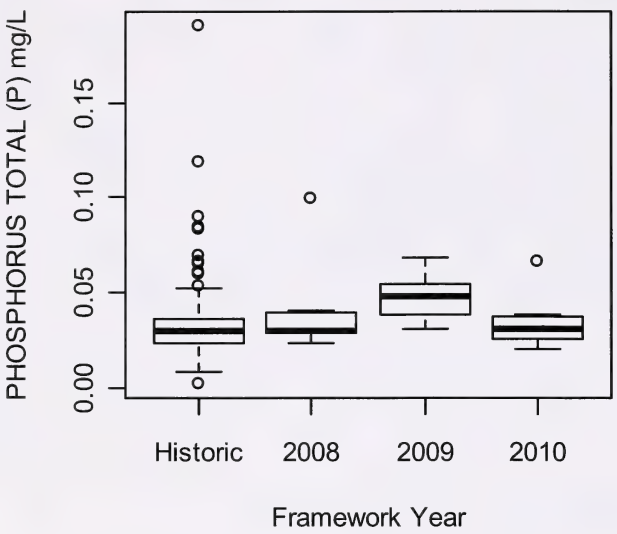

OIL AND GREASE mg/L
0.0
1.0
2.0
3.0
Historic
2008
2009
2010
Framework Year

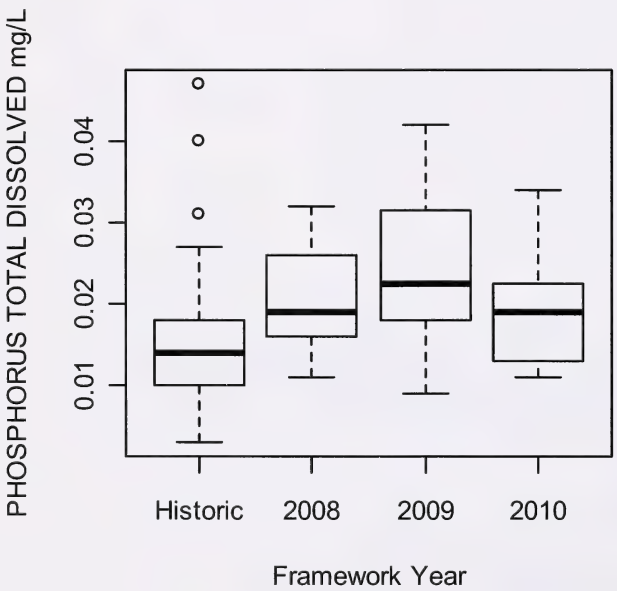

OXYGEN BIOCHEMICAL DEMAND mg/L
0.5
1.5
2.5
3.5
Historic
2008
2009
2010
Framework Year

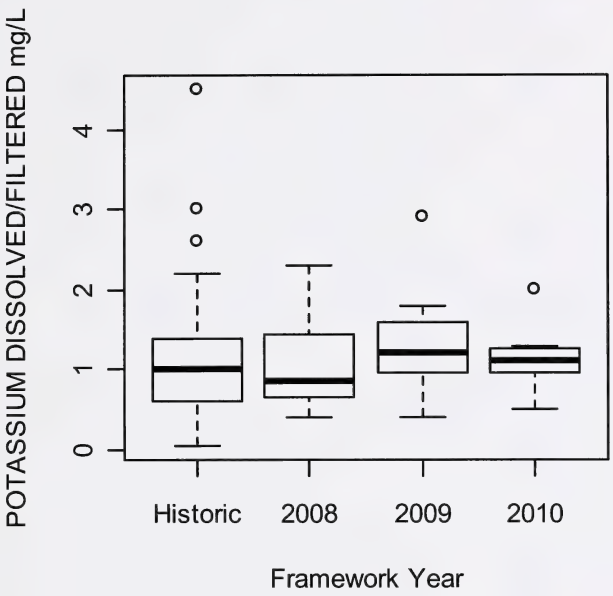

OXYGEN TOTAL COD mg/L
50
100
150
Historic
2008
2009
2010
Framework Year

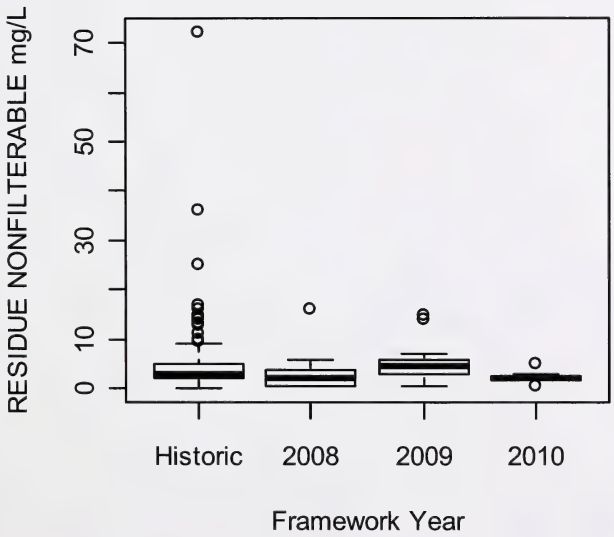

pH
7.0
7.5
8.0
8.5
Historic
2008
2009
2010
Framework Year

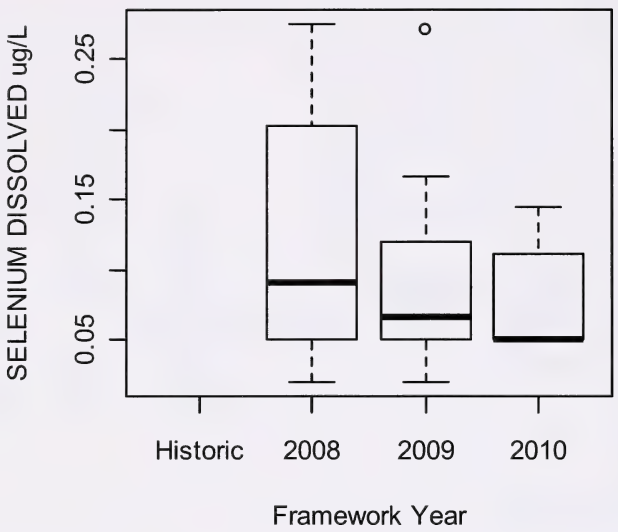

PHOSPHORUS PARTICULATE (CALCD_) mg/L
0.02
0.04
0.06
0.08
Historic
2008
2009
2010
Framework Year

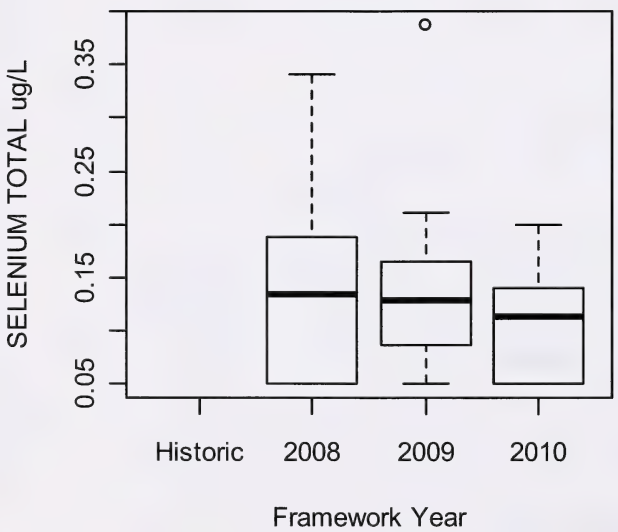

PHOSPHORUS TOTAL (P) mg/L
0.00
0.05
0.10
0.15
Historic
2008
2009
2010
Framework Year

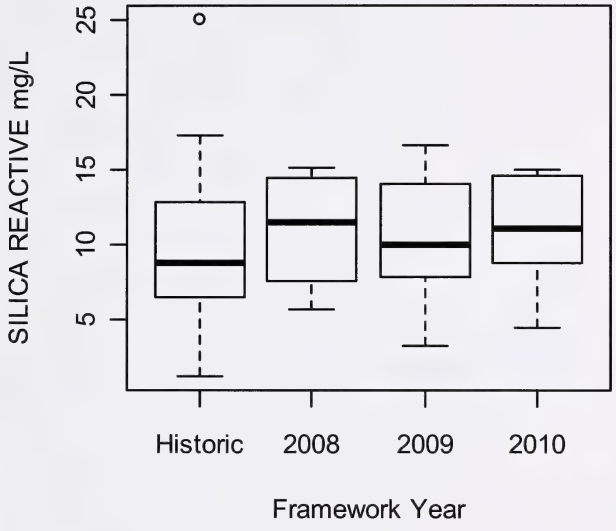

PHOSPHORUS TOTAL DISSOLVED mg/L
0.01
0.02
0.03
0.04
Historic
2008
2009
2010
Framework Year

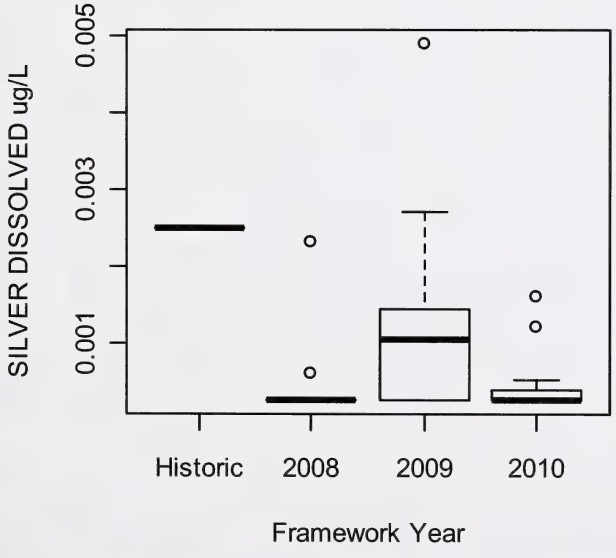

POTASSIUM DISSOLVED/FILTERED mg/L
0
1
2
3
4
Historic
2008
2009
2010
Framework Year

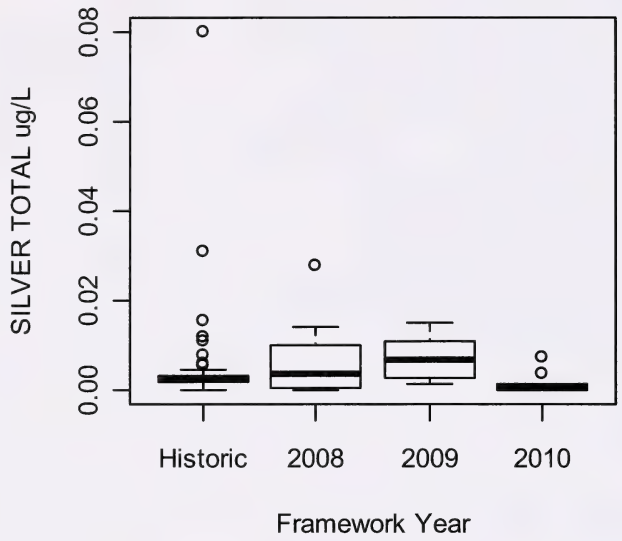

RESIDUE NONFILTERABLE mg/L
0
10
30
50
70
Historic
2008
2009
2010
Framework Year

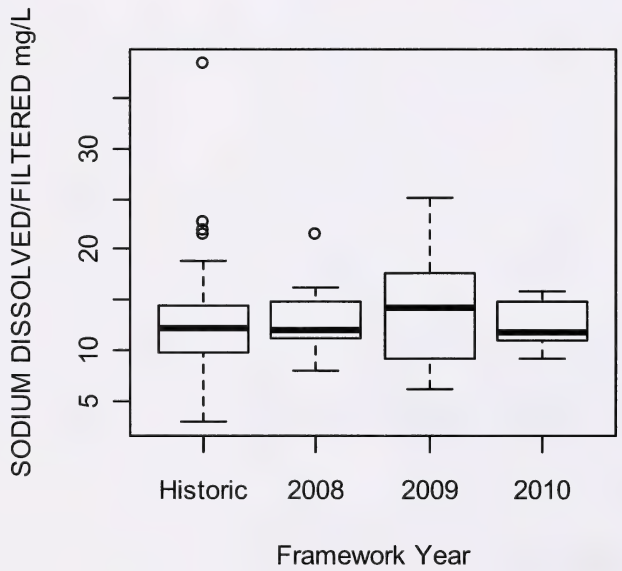

SELENIUM DISSOLVED ug/L
0.05
0.15
0.25
Historic
2008
2009
2010
Framework Year

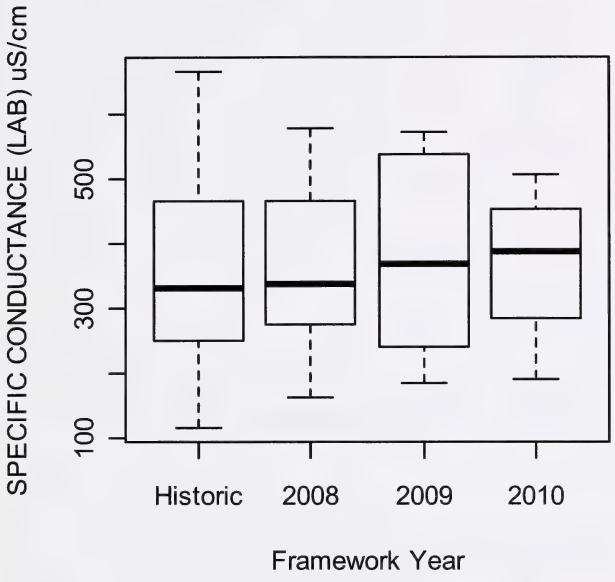

SELENIUM TOTAL ug/L
0.05
0.15
0.25
0.35
Historic
2008
2009
2010
Framework Year

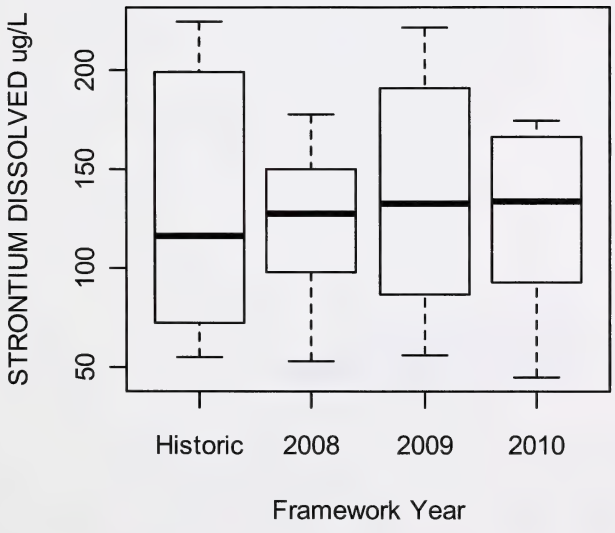

SILICA REACTIVE mg/L
5
10
15
20
25
Historic
2008
2009
2010
Framework Year

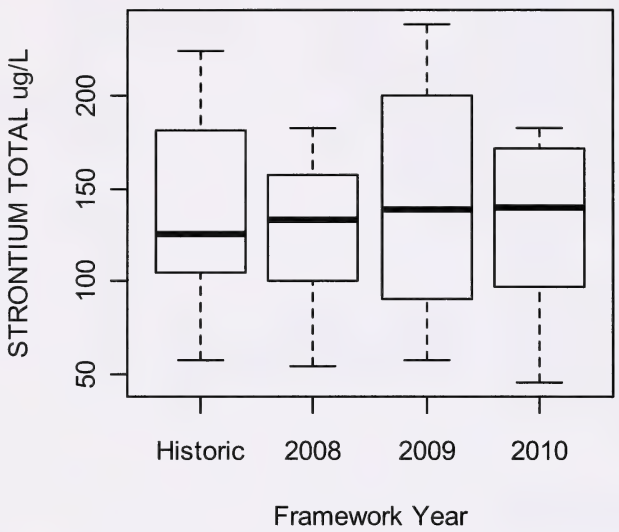

SILVER DISSOLVED ug/L
0.001
0.003
0.005
Historic
2008
2009
2010
Framework Year

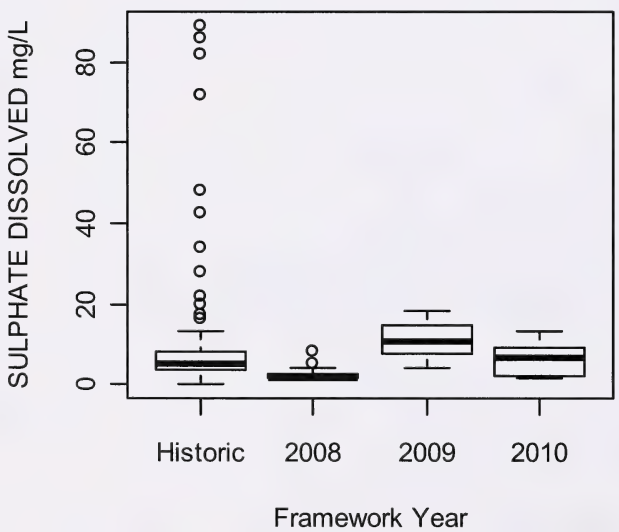

SILVER TOTAL ug/L
0.00
0.02
0.04
0.06
0.08
Historic
2008
2009
2010
Framework Year

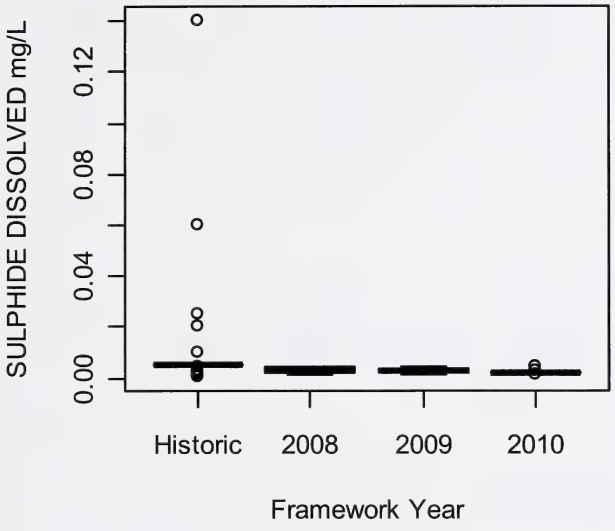

SODIUM DISSOLVED/FILTERED mg/L
5
10
20
30
Historic
2008
2009
2010
Framework Year

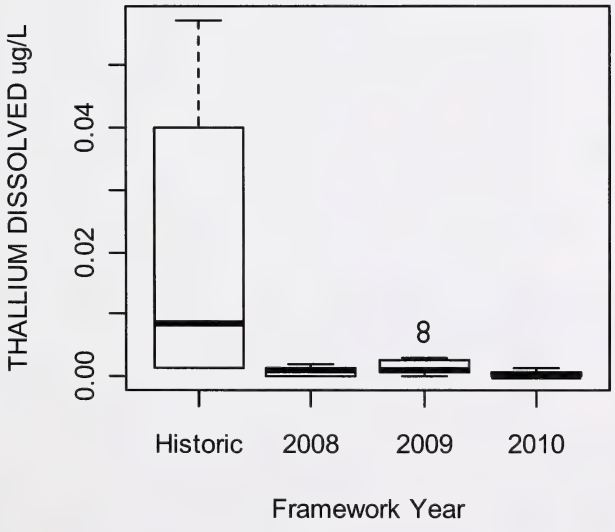

SPECIFIC CONDUCTANCE (LAB) uS/cm
100
300
500
Historic
2008
2009
2010
Framework Year

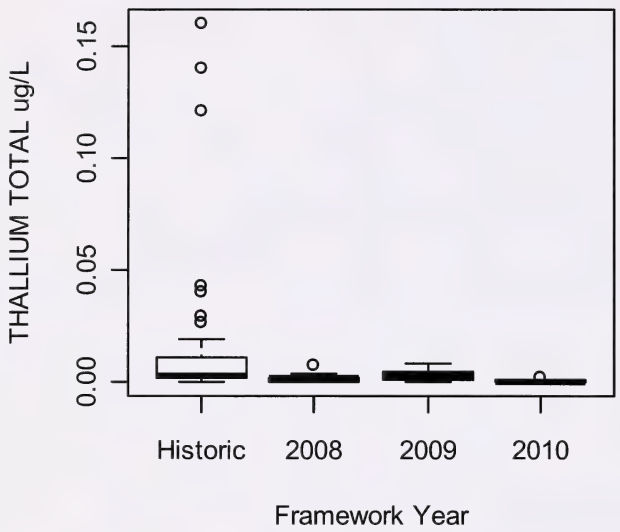

STRONTIUM DISSOLVED ug/L
50
100
150
200
Historic
2008
2009
2010
Framework Year

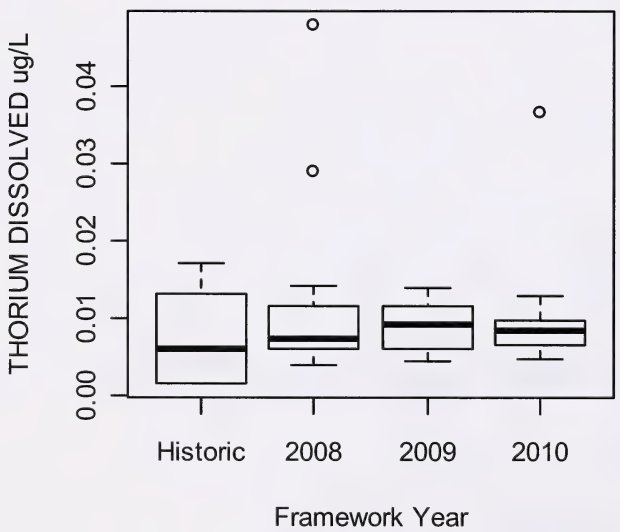

STRONTIUM TOTAL ug/L
50
100
150
200
Historic
2008
2009
2010
Framework Year

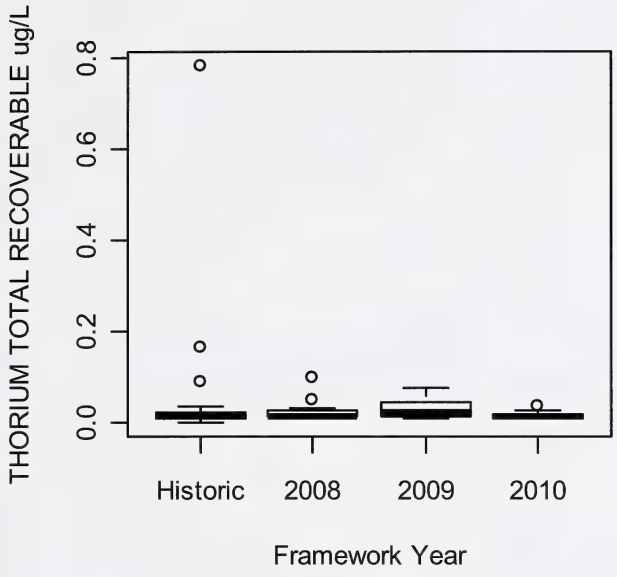

SULPHATE DISSOLVED mg/L
0
20
40
60
80
Historic
2008
2009
2010
Framework Year

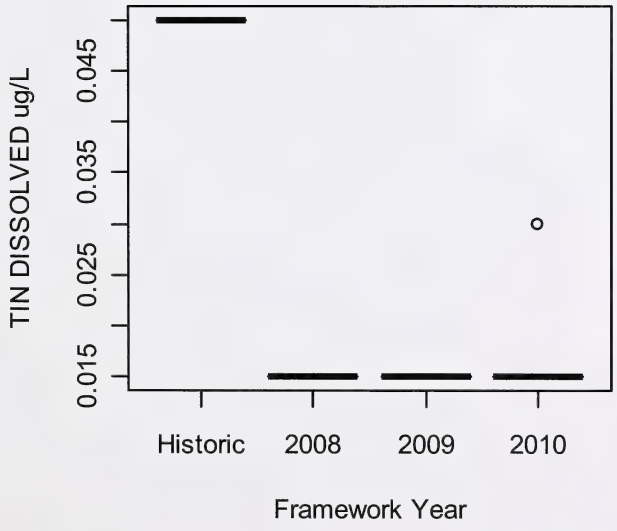

SULPHIDE DISSOLVED mg/L
0.00
0.04
0.08
0.12
Historic
2008
2009
2010
Framework Year

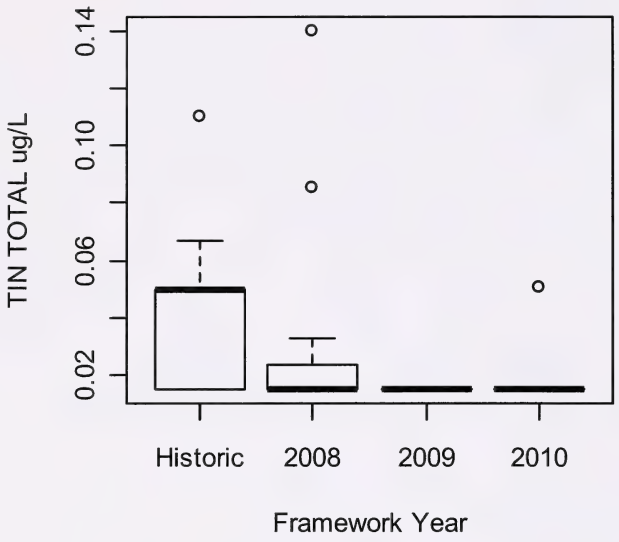

THALLIUM DISSOLVED ug/L
0.00
0.02
0.04
Historic
2008
2009
2010
Framework Year

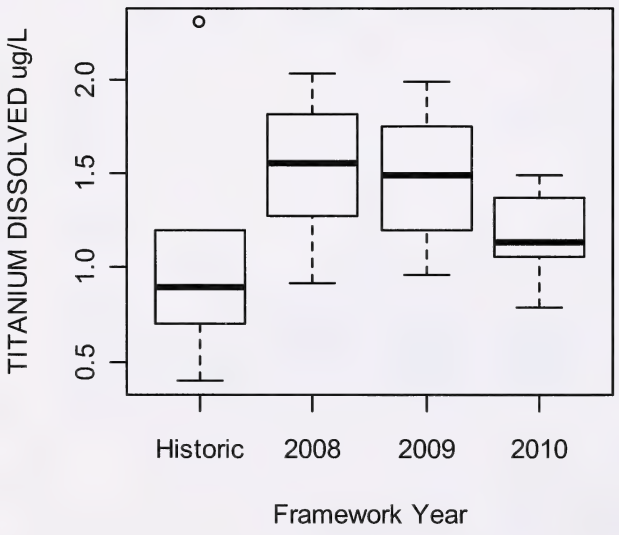

THALLIUM TOTAL ug/L
0.00
0.05
0.10
0.15
Historic
2008
2009
2010
Framework Year

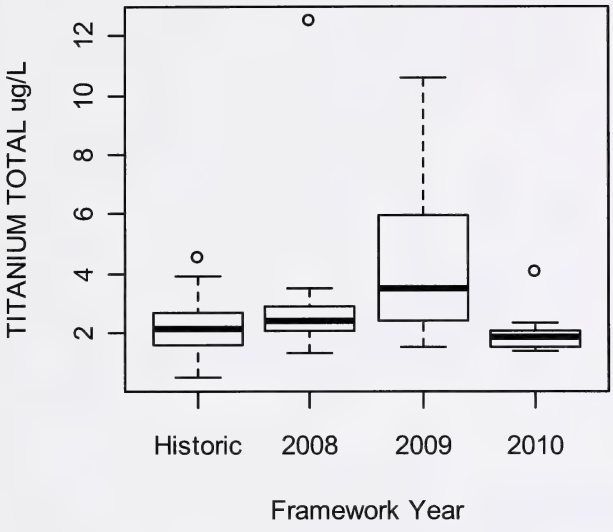

THORIUM DISSOLVED ug/L
0.00
0.01
0.02
0.03
0.04
Historic
2008
2009
2010
Framework Year

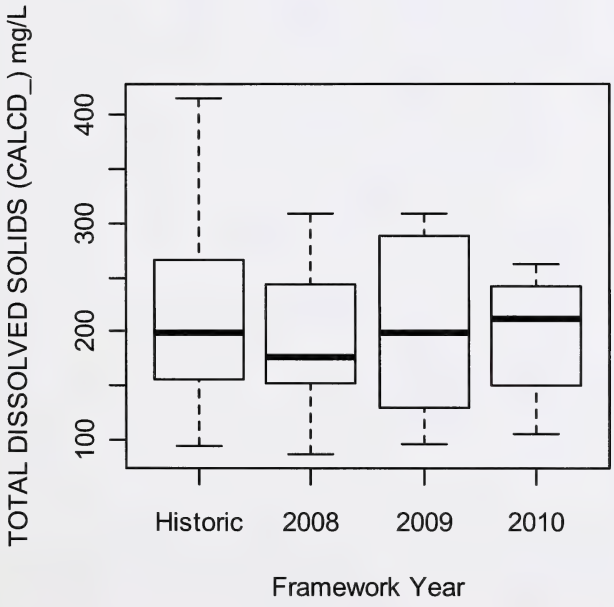

THORIUM TOTAL RECOVERABLE ug/L
0.0
0.2
0.4
0.6
0.8
Historic
2008
2009
2010
Framework Year

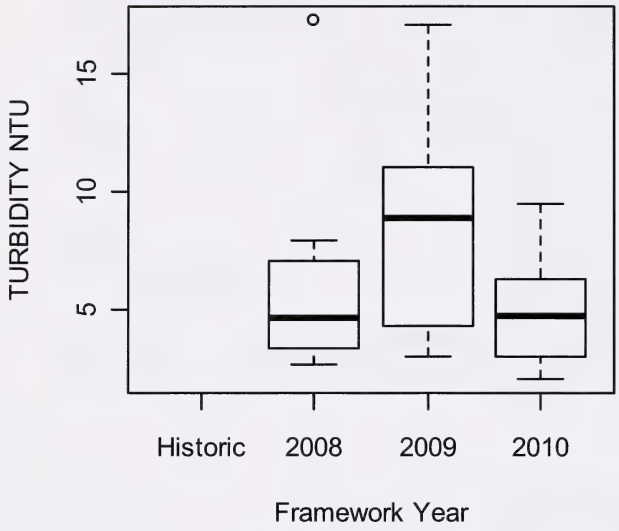

TIN DISSOLVED ug/L
0.015
0.025
0.035
0.045
Historic
2008
2009
2010
Framework Year

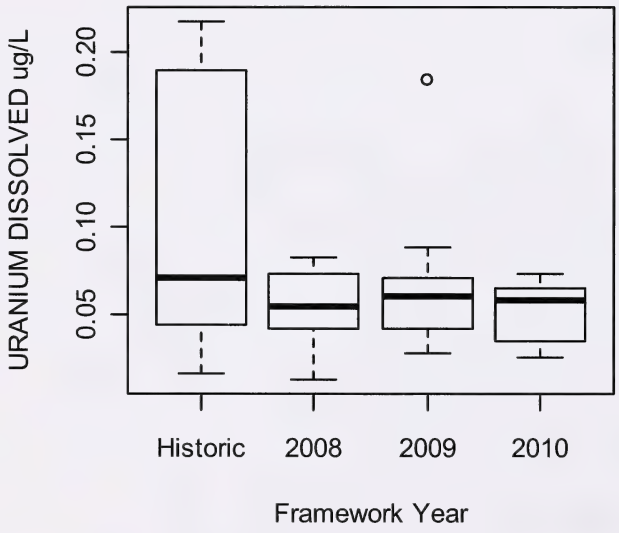

TIN TOTAL ug/L
0.02
0.06
0.10
0.14
Historic
2008
2009
2010
Framework Year

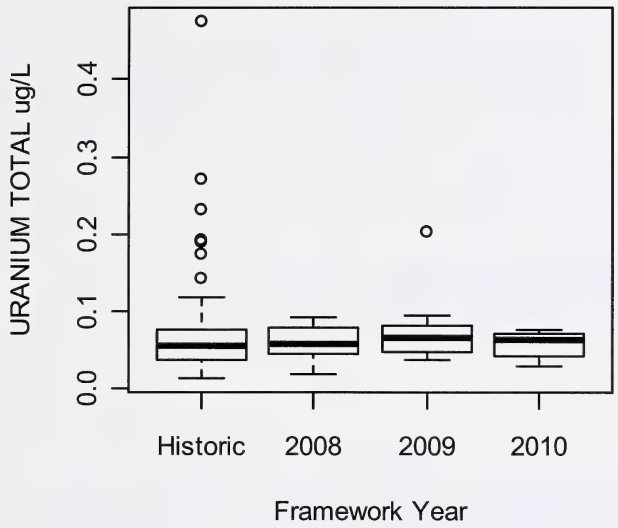

TITANIUM DISSOLVED ug/L
0.5
1.0
1.5
2.0
Historic
2008
2009
2010
Framework Year

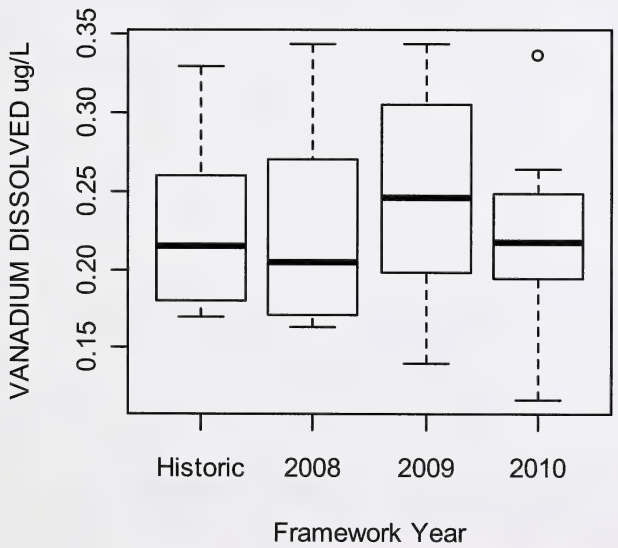

TITANIUM TOTAL ug/L
2
4
6
8
10
12
Historic
2008
2009
2010
Framework Year

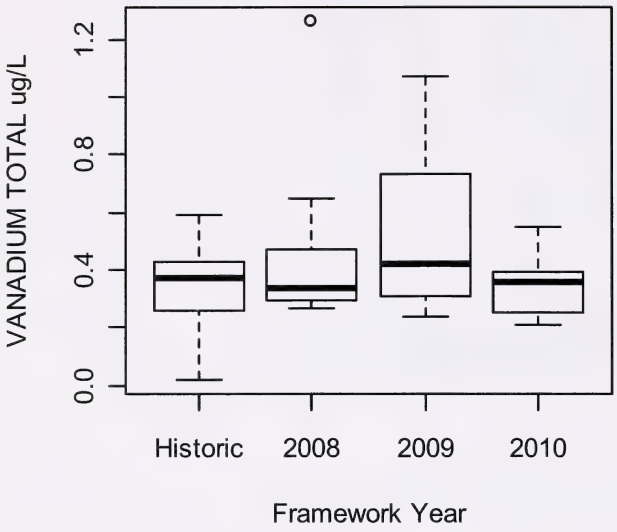

TOTAL DISSOLVED SOLIDS (CALCD_) mg/L
100
200
300
400
Historic
2008
2009
2010
Framework Year

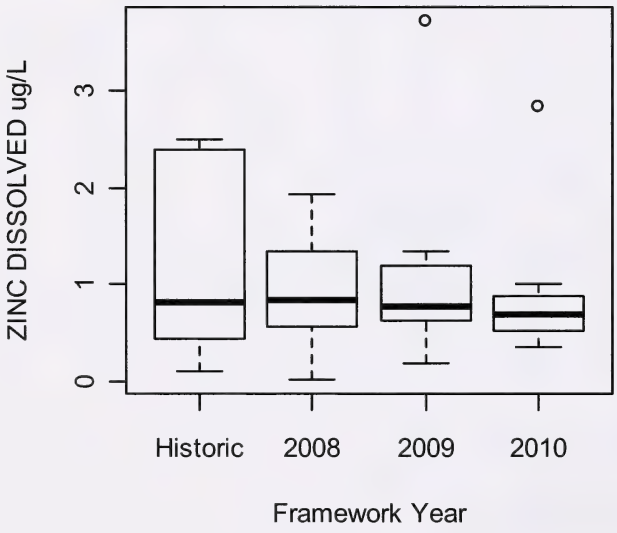

TURBIDITY NTU
5
10
15
Historic
2008
2009
2010
Framework Year


URANIUM DISSOLVED ug/L
0.05
0.10
0.15
0.20
Historic
2008
2009
2010
Framework Year

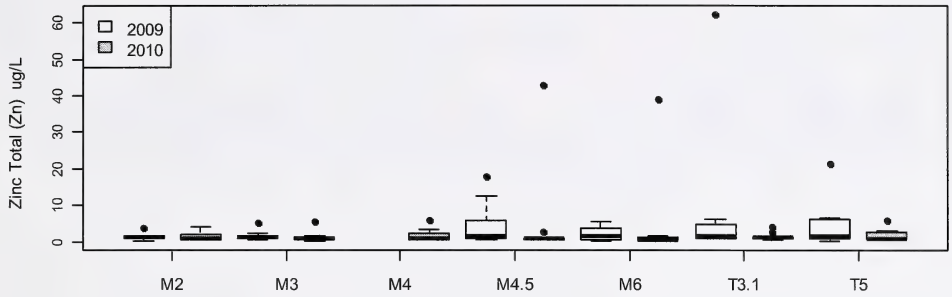

URANIUM TOTAL ug/L
0.0
0.1
0.2
0.3
0.4
Historic
2008
2009
2010
Framework Year

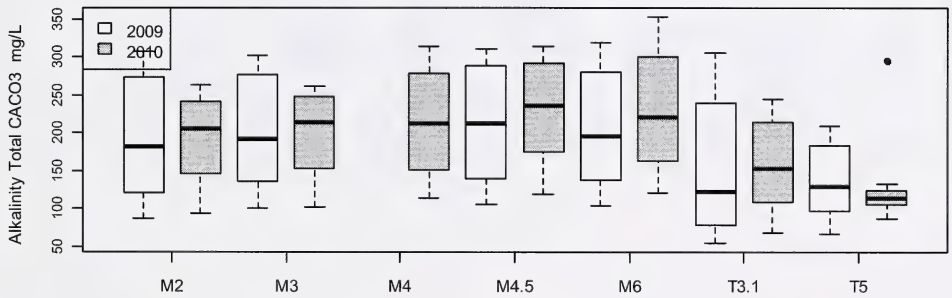

VANADIUM DISSOLVED ug/L
0.15
0.20
0.25
0.30
0.35
Historic
2008
2009
2010
Framework Year

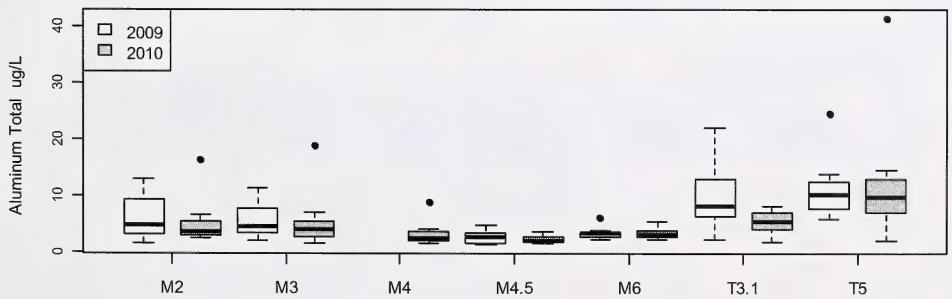

VANADIUM TOTAL ug/L
0.0
0.4
0.8
1.2
Historic
2008
2009
2010
Framework Year

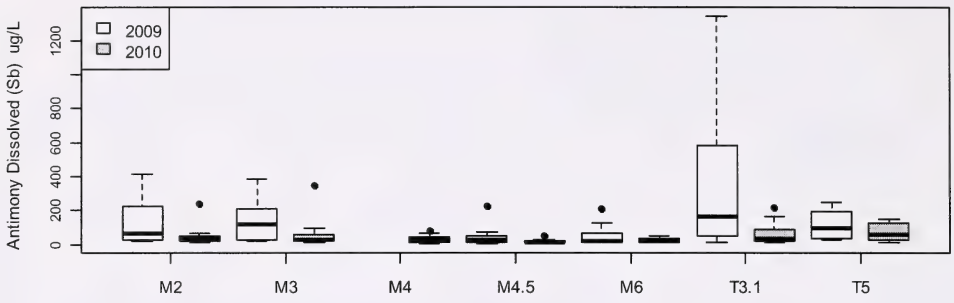

ZINC DISSOLVED ug/L
0
1
2
3
Historic
2008
2009
2010
Framework Year

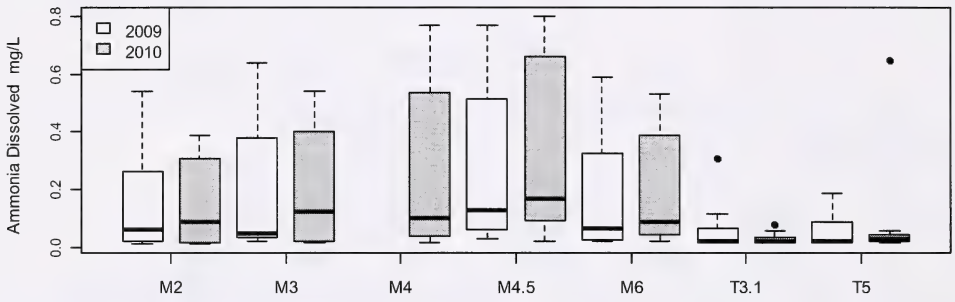
APPENDIX 4. LONGITUDINAL (SITE BY SITE) COMPARISON OF CONSTITUENT CONCENTRATIONS FOR 2009 AND 2010

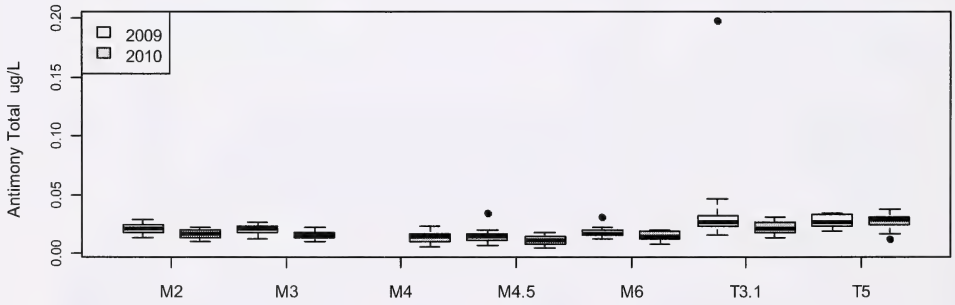


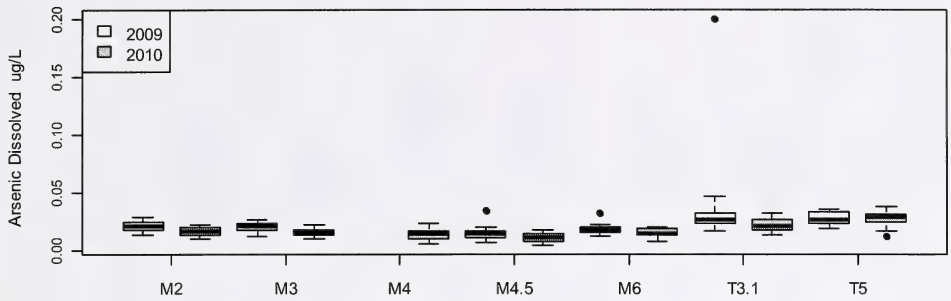


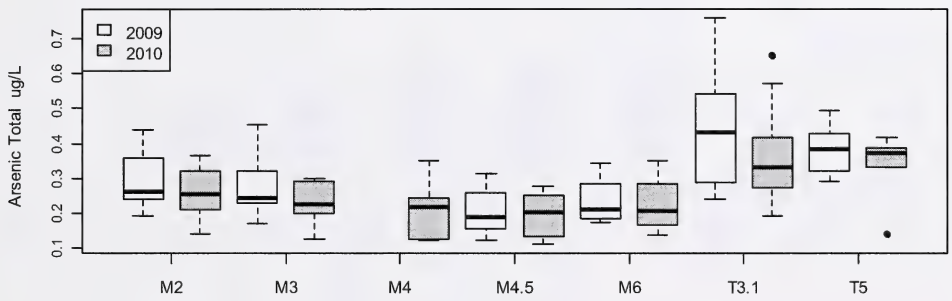


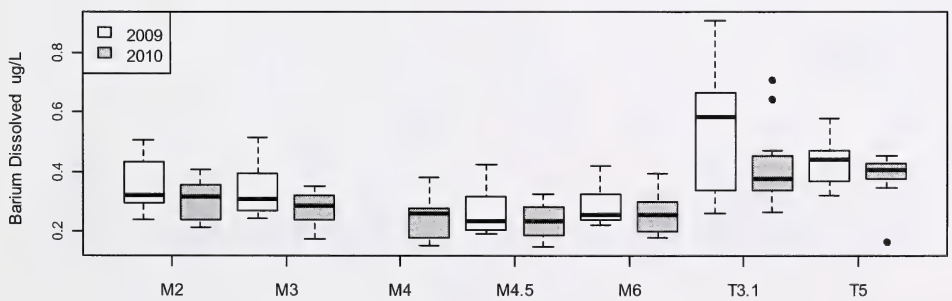

Antimony Dissolved (Sb) ug/L
2009
2010
0
200
400
600
800
1200
M2
M3
M4
M4.5
M6
T3.1
T5

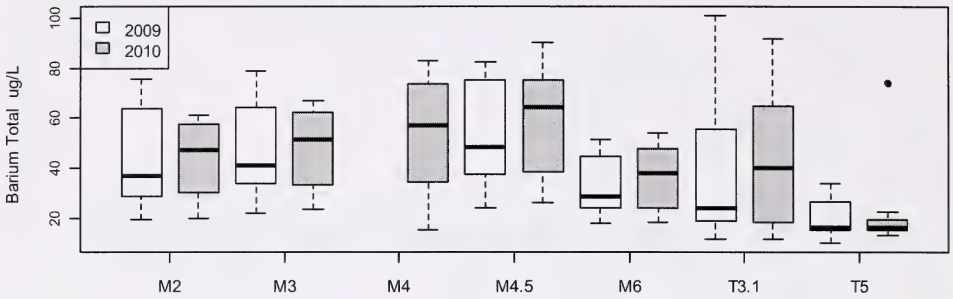

Ammonia Dissolved mg/L
2009
2010
0.0
0.2
0.4
0.6
0.8
M2
M3
M4
M4.5
M6
T3.1
T5

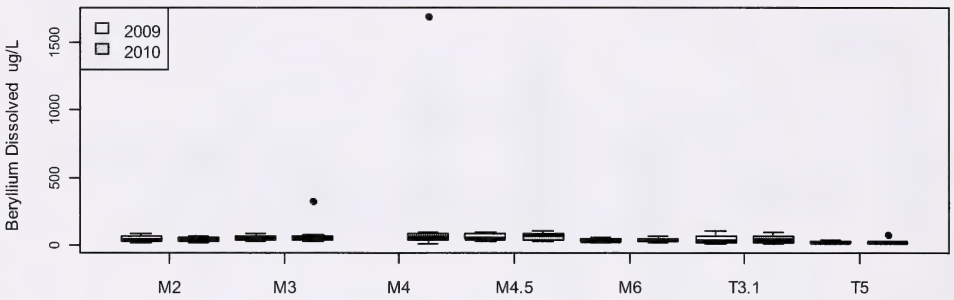

Antimony Total ug/L
2009
2010
0.00
0.05
0.10
0.15
0.20
M2
M3
M4
M4.5
M6
T3.1
T5

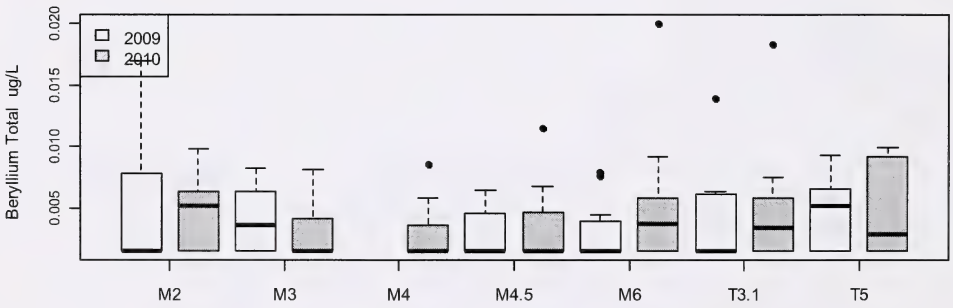

Arsenic Dissolved ug/L
2009
2010
0.00
0.05
0.10
0.15
0.20
M2
M3
M4
M4.5
M6
T3.1
T5

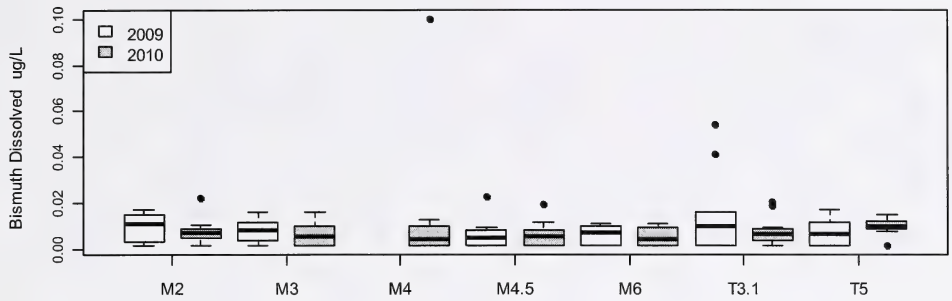

Arsenic Total ug/L
2009
2010
0.1
0.2
0.3
0.4
0.5
0.6
0.7
M2
M3
M4
M4.5
M6
T3.1
T5

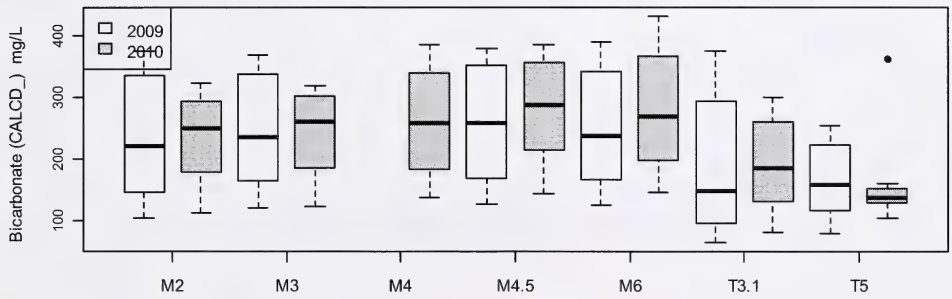

Barium Dissolved ug/L
2009
2010
0.2
0.4
0.6
0.8
M2
M3
M4
M4.5
M6
T3.1
T5

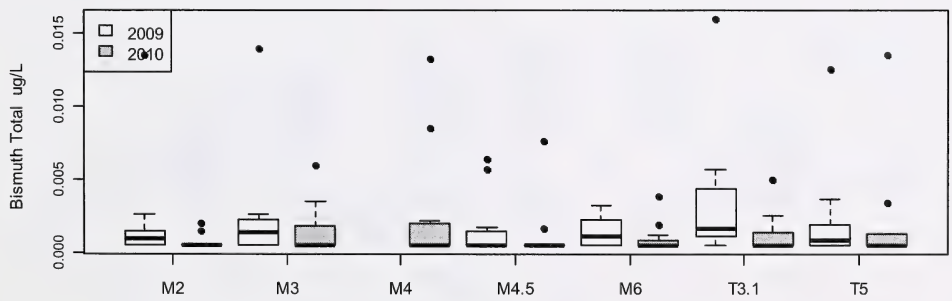

Barium Total ug/L
2009
2010
20
40
60
80
100
M2
M3
M4
M4.5
M6
T3.1
T5

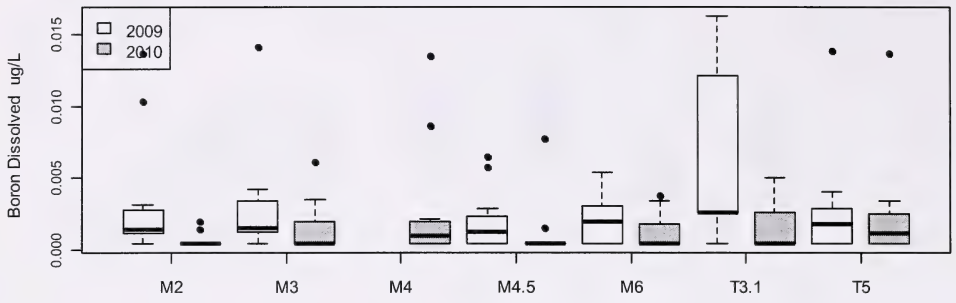

Beryllium Dissolved ug/L
2009
2010
0
500
1000
1500
M2
M3
M4
M4.5
M6
T3.1
T5

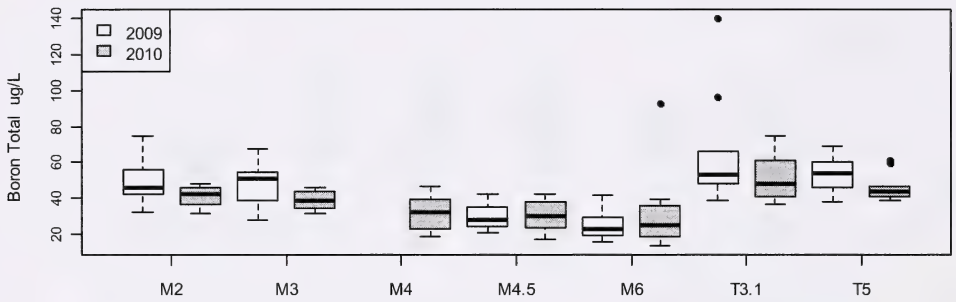

Beryllium Total ug/L
2009
2010
0.005
0.010
0.015
0.020
M2
M3
M4
M4.5
M6
T3.1
T5

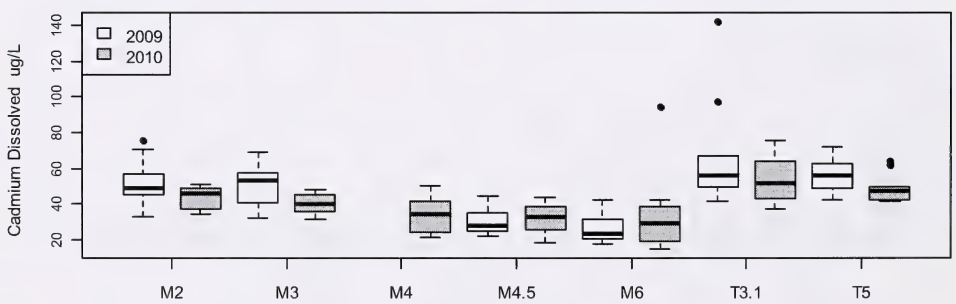

Bismuth Dissolved ug/L
2009
2010
0.00
0.02
0.04
0.06
0.08
0.10
M2
M3
M4
M4.5
M6
T3.1
T5

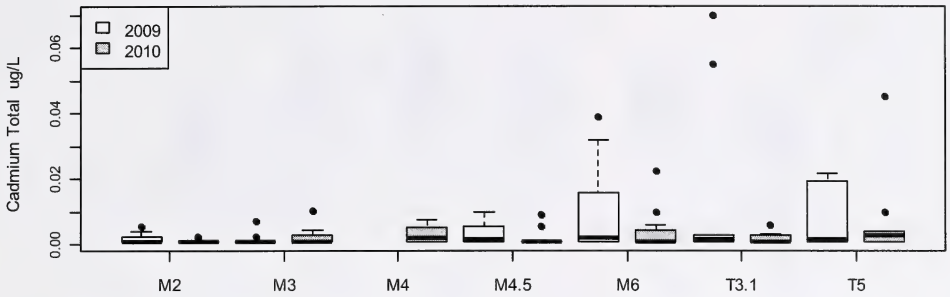

Bicarbonate (CALCD_) mg/L
2009
2010
100
200
300
400
M2
M3
M4
M4.5
M6
T3.1
T5

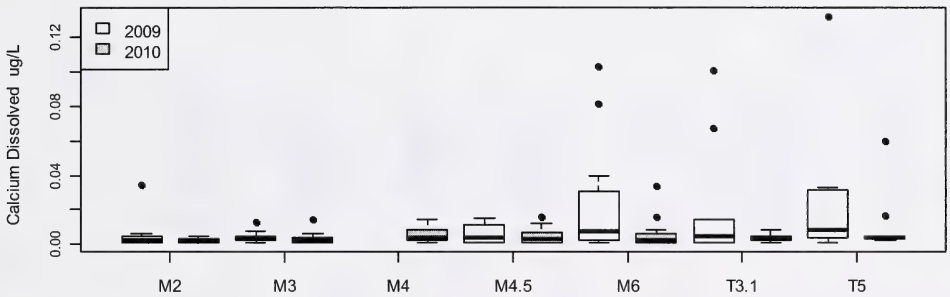

Bismuth Total ug/L
2009
2010
0.000
0.005
0.010
0.015
M2
M3
M4
M4.5
M6
T3.1
T5

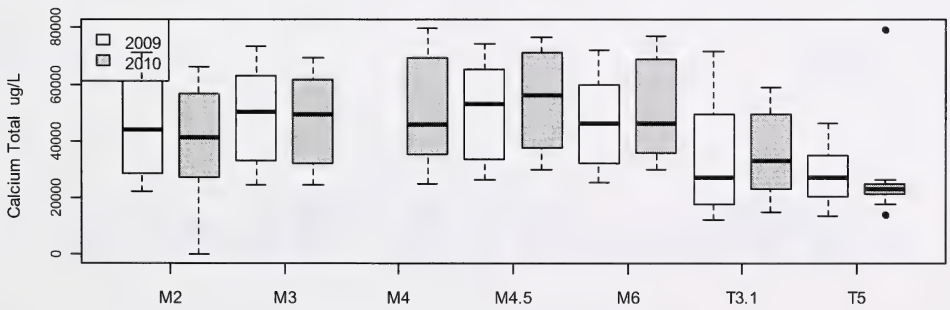

Boron Dissolved ug/L
2009
2010
0.000
0.005
0.010
0.015
M2
M3
M4
M4.5
M6
T3.1
T5

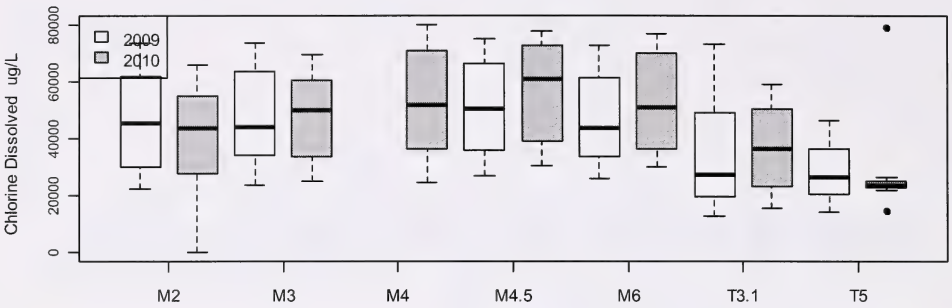

Boron Total ug/L
2009
2010
20
40
60
80
100
120
140
M2
M3
M4
M4.5
M6
T3.1
T5

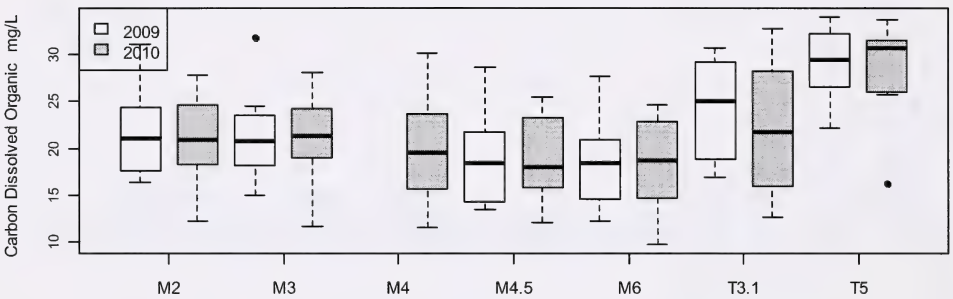

Cadmium Dissolved ug/L
2009
2010
20
40
60
80
100
120
140
M2
M3
M4
M4.5
M6
T3.1
T5

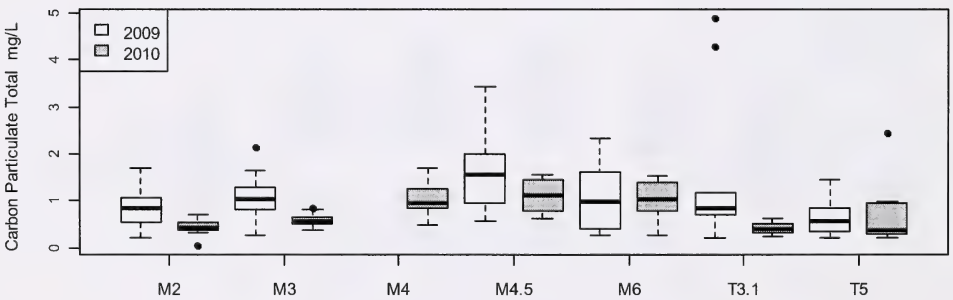

Cadmium Total ug/L
2009
2010
0.00
0.02
0.04
0.06
M2
M3
M4
M4.5
M6
T3.1
T5

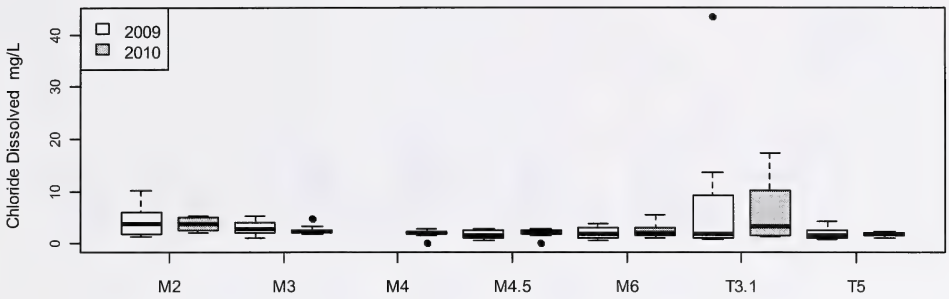

Calcium Dissolved ug/L
2009
2010
0.00
0.04
0.08
0.12
M2
M3
M4
M4.5
M6
T3.1
T5

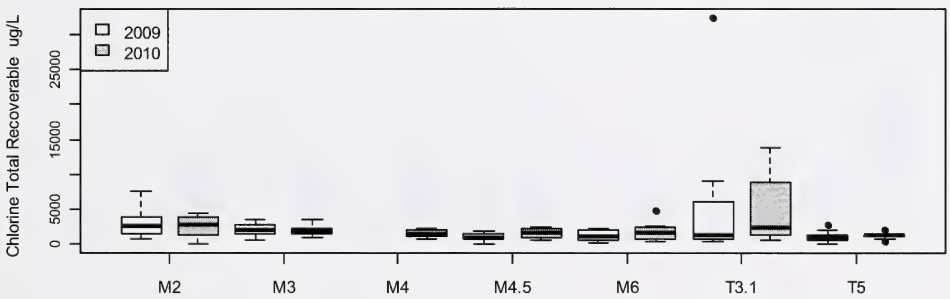

Calcium Total ug/L
2009
2010
0
20000
40000
60000
80000
M2
M3
M4
M4.5
M6
T3.1
T5

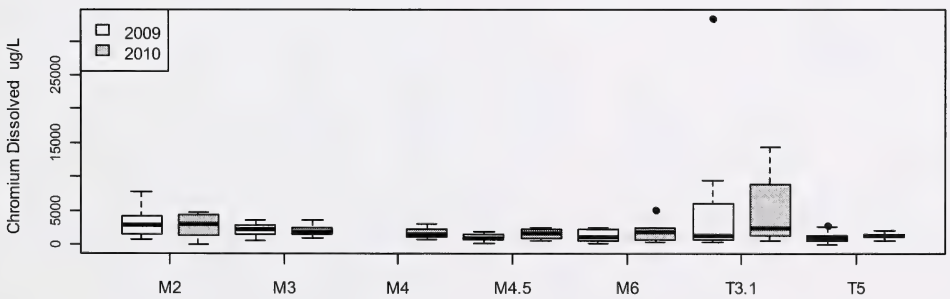

Chlorine Dissolved ug/L
0
20000
40000
60000
80000
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

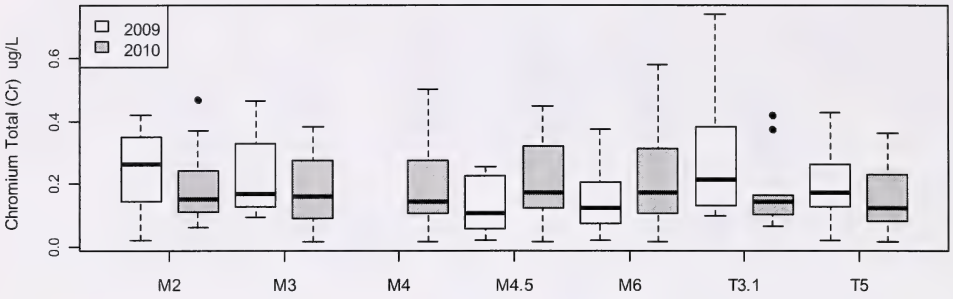

Carbon Dissolved Organic mg/L
10
15
20
25
30
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

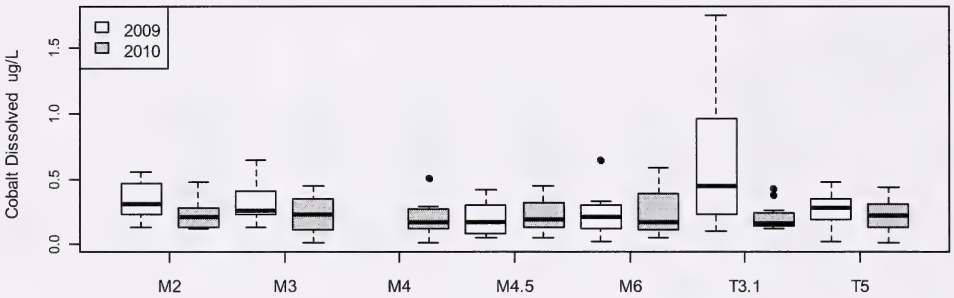

Carbon Particulate Total mg/L
0
1
2
3
4
5
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

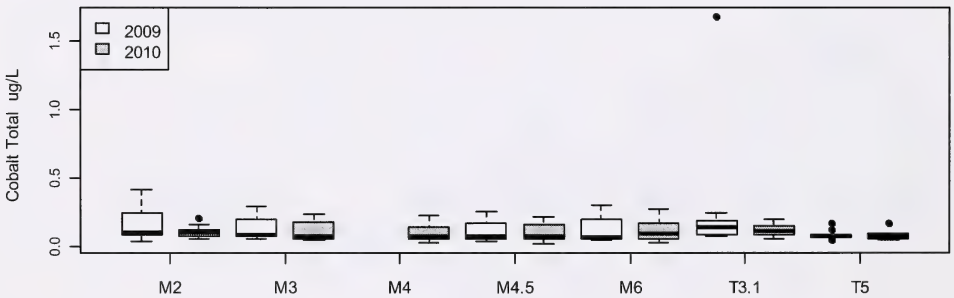

Chloride Dissolved mg/L
2009
2010
0
10
20
30
40
M2
M3
M4
M4.5
M6
T3.1
T5

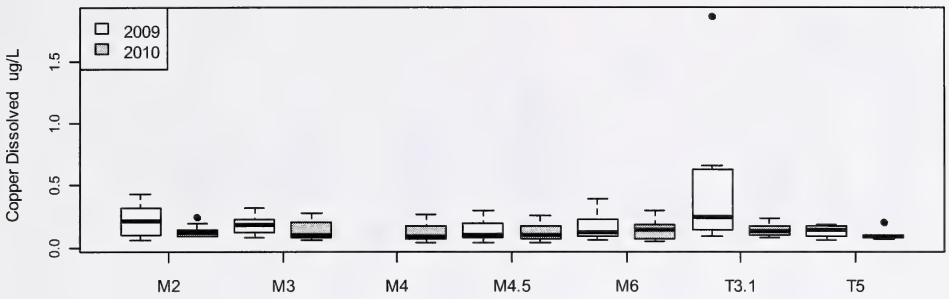

Chlorine Total Recoverable ug/L
2009
2010
0
5000
15000
25000
M2
M3
M4
M4.5
M6
T3.1
T5

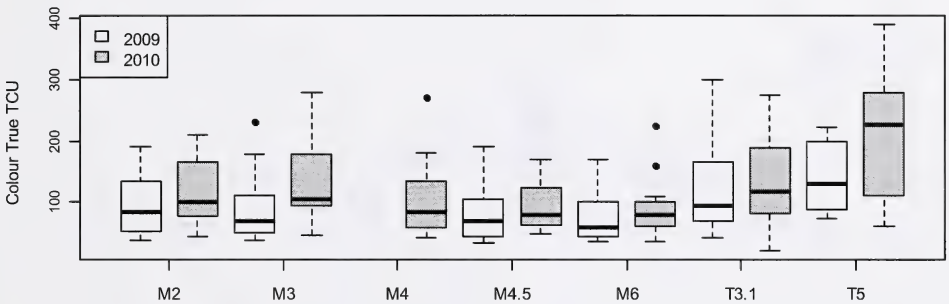

Chromium Dissolved ug/L
2009
2010
0
5000
15000
25000
M2
M3
M4
M4.5
M6
T3.1
T5

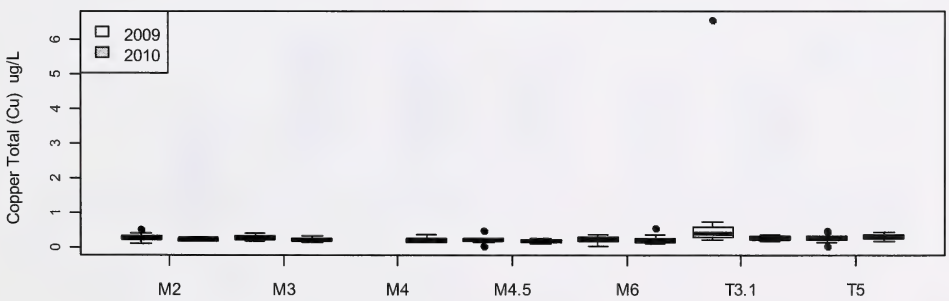

2009
2010
Chromium Total (Cr) ug/L
0.0
0.2
0.4
0.6
M2
M3
M4
M4.5
M6
T3.1
T5

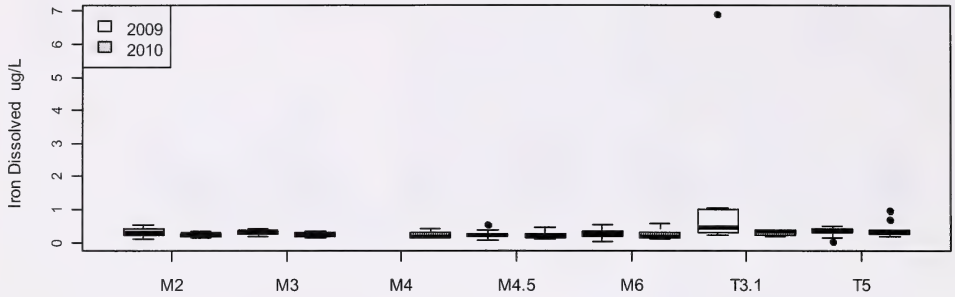

2009
2010
Cobalt Dissolved ug/L
0.0
0.5
1.0
1.5
M2
M3
M4
M4.5
M6
T3.1
T5

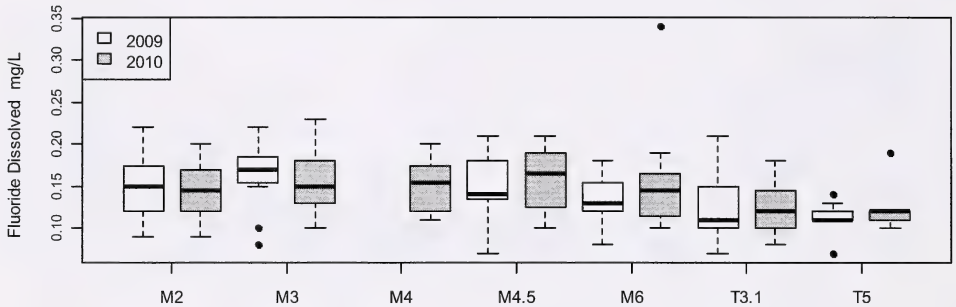

2009
2010
Cobalt Total ug/L
0.0
0.5
1.0
1.5
M2
M3
M4
M4.5
M6
T3.1
T5

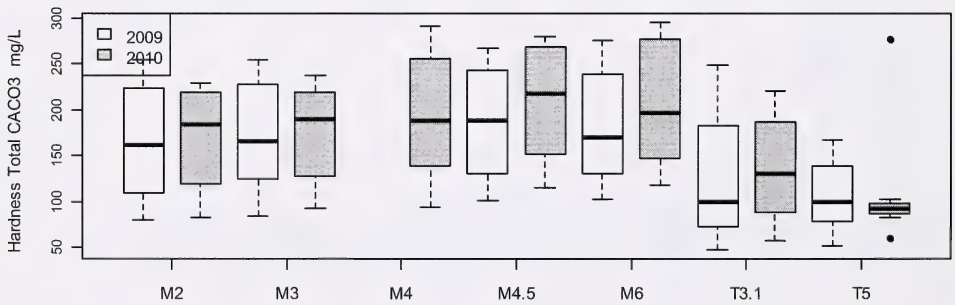

Copper Dissolved ug/L
2009
2010
0.0
0.5
1.0
1.5
M2
M3
M4
M4.5
M6
T3.1
T5

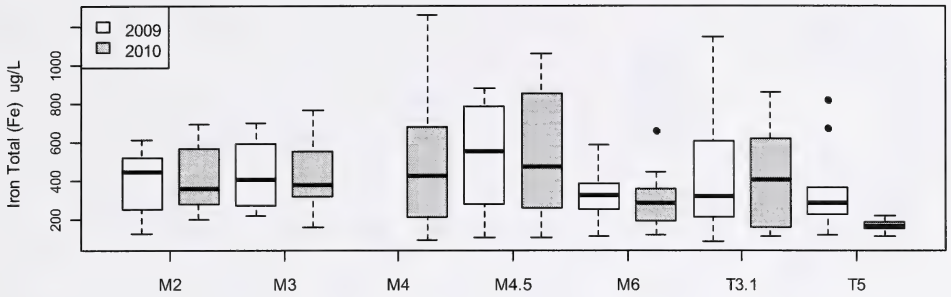

Colour True TCU
2009
2010
100
200
300
400
M2
M3
M4
M4.5
M6
T3.1
T5

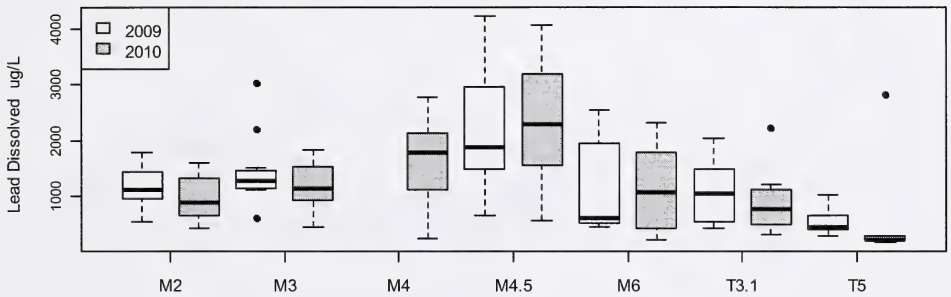

Copper Total (Cu) ug/L
2009
2010
0
1
2
3
4
5
6
M2
M3
M4
M4.5
M6
T3.1
T5

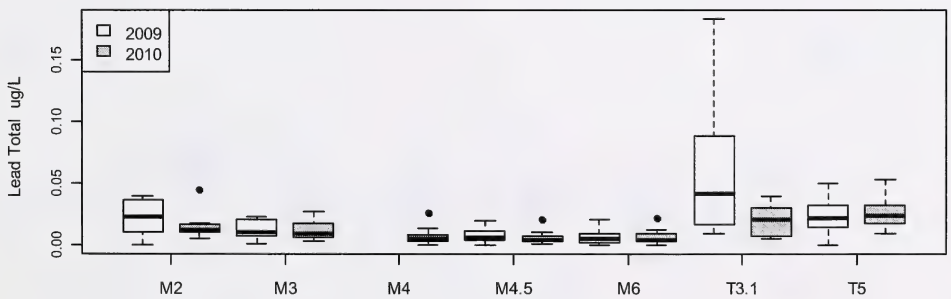

Iron Dissolved ug/L
2009
2010
0
1
2
3
4
5
6
7
M2
M3
M4
M4.5
M6
T3.1
T5

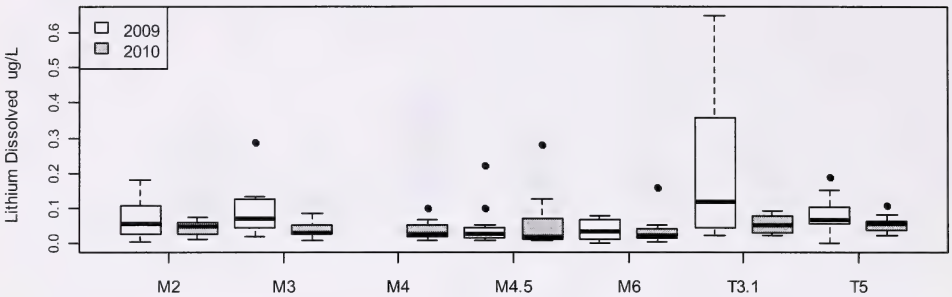

Fluoride Dissolved mg/L
2009
2010
0.10
0.15
0.20
0.25
0.30
0.35
M2
M3
M4
M4.5
M6
T3.1
T5

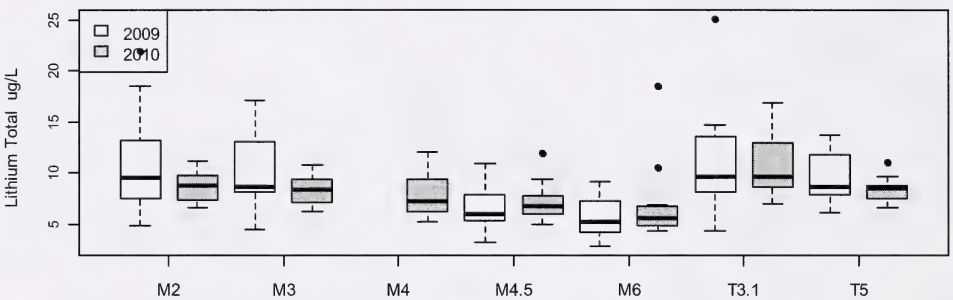

Hardness Total CACO3 mg/L
2009
2010
50
100
150
200
250
300
M2
M3
M4
M4.5
M6
T3.1
T5

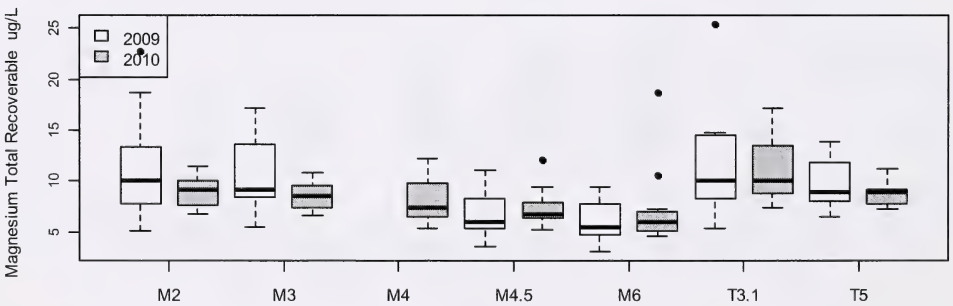

Iron Total (Fe) ug/L
2009
2010
200
400
600
800
1000
M2
M3
M4
M4.5
M6
T3.1
T5

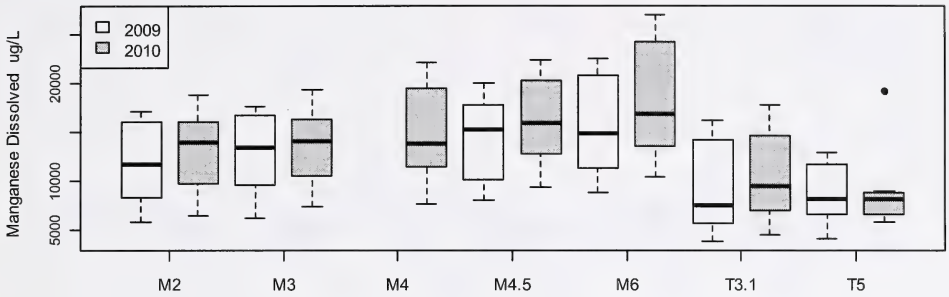

Lead Dissolved ug/L
2009
2010
1000
2000
3000
4000
M2
M3
M4
M4.5
M6
T3.1
T5

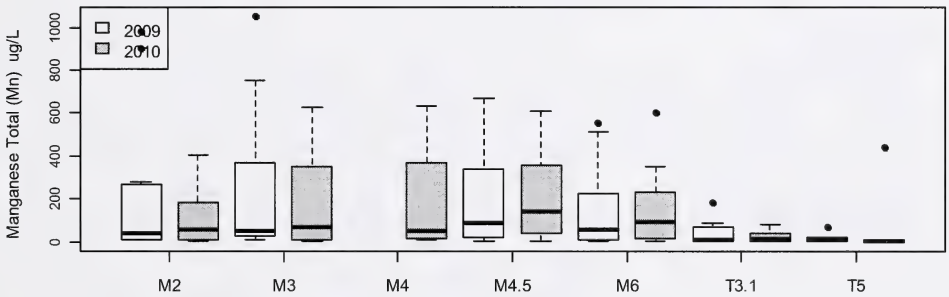

Lead Total ug/L
2009
2010
0.00
0.05
0.10
0.15
M2
M3
M4
M4.5
M6
T3.1
T5

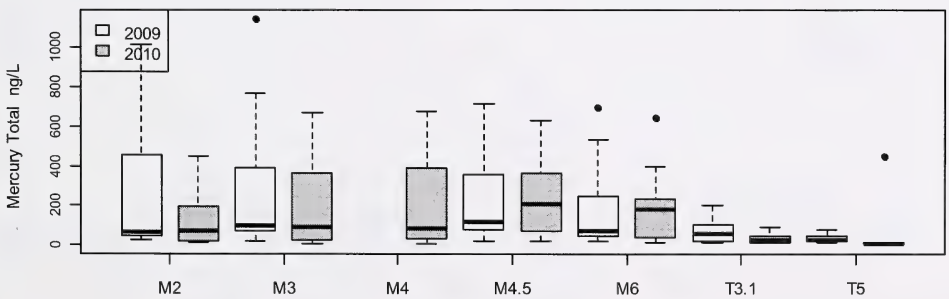

Lithium Dissolved ug/L
2009
2010
0.0
0.1
0.2
0.3
0.4
0.5
0.6
M2
M3
M4
M4.5
M6
T3.1
T5

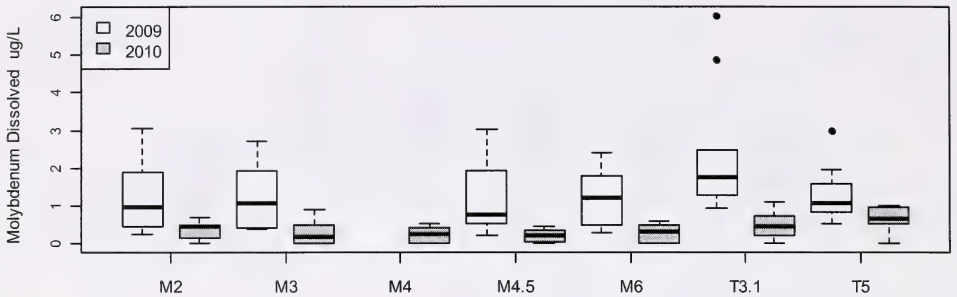

Lithium Total ug/L
2009
2010
5
10
15
20
25
M2
M3
M4
M4.5
M6
T3.1
T5

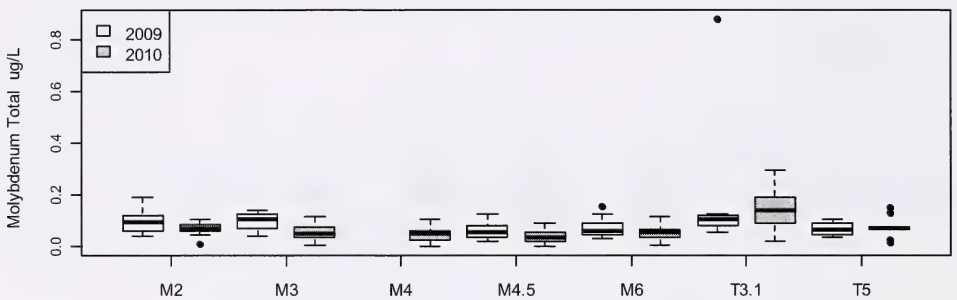

Magnesium Total Recoverable ug/L
2009
2010
5
10
15
20
25
M2
M3
M4
M4.5
M6
T3.1
T5

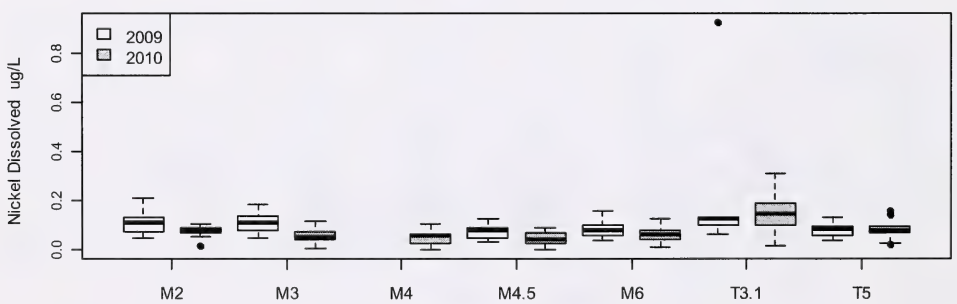

Manganese Dissolved ug/L
2009
2010
5000
10000
20000
M2
M3
M4
M4.5
M6
T3.1
T5

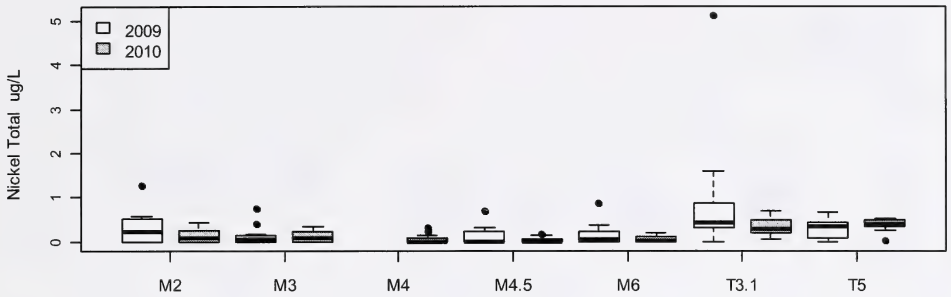

Manganese Total (Mn) ug/L
2009
2010
0
200
400
600
800
1000
M2
M3
M4
M4.5
M6
T3.1
T5

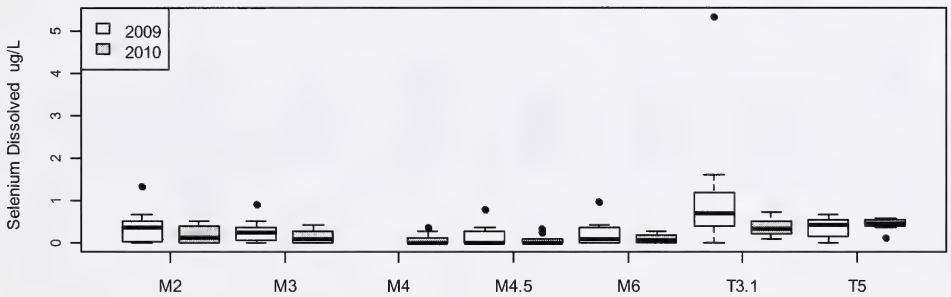

Mercury Total ng/L
2009
2010
0
200
400
600
800
1000
M2
M3
M4
M4.5
M6
T3.1
T5

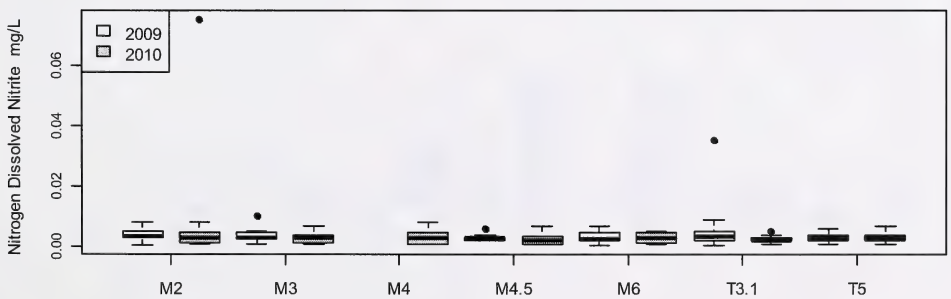

Molybdenum Dissolved ug/L
2009
2010
0
1
2
3
4
5
6
M2
M3
M4
M4.5
M6
T3.1
T5

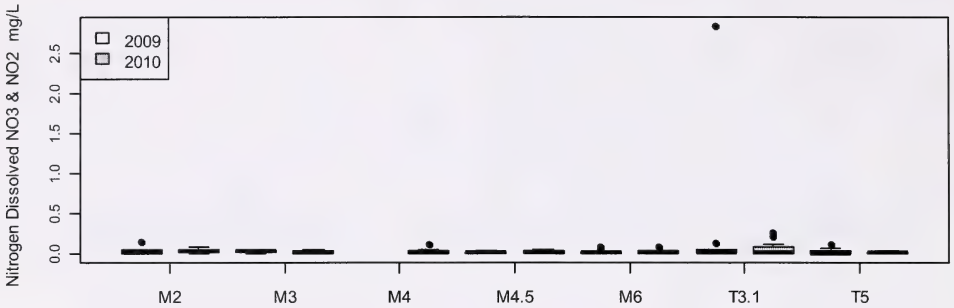

Molybdenum Total ug/L
2009
2010
0.0
0.2
0.4
0.6
0.8
M2
M3
M4
M4.5
M6
T3.1
T5

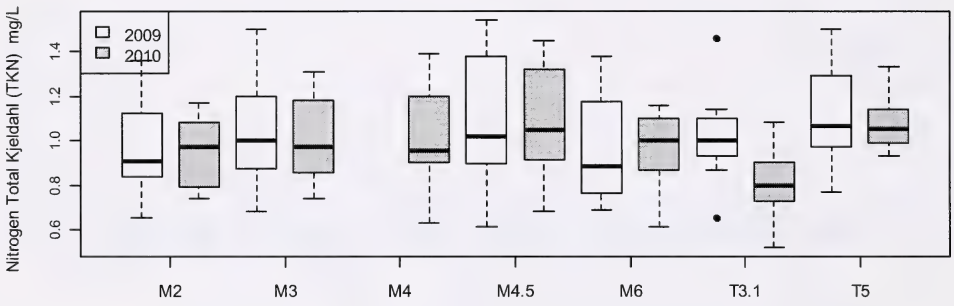

Nickel Dissolved ug/L
2009
2010
0.0
0.2
0.4
0.6
0.8
M2
M3
M4
M4.5
M6
T3.1
T5

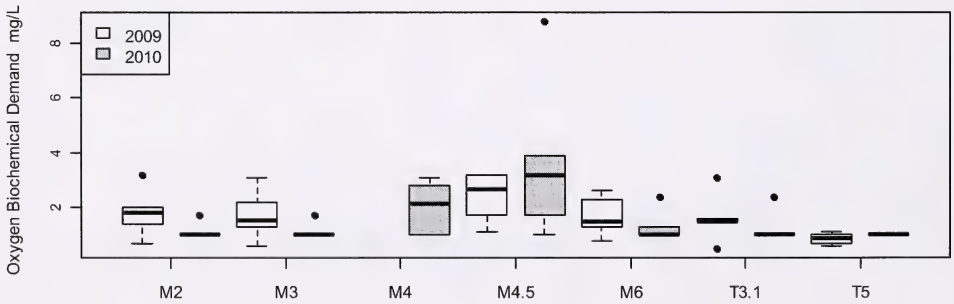

Nickel Total ug/L
2009
2010
0
1
2
3
4
5
M2
M3
M4
M4.5
M6
T3.1
T5

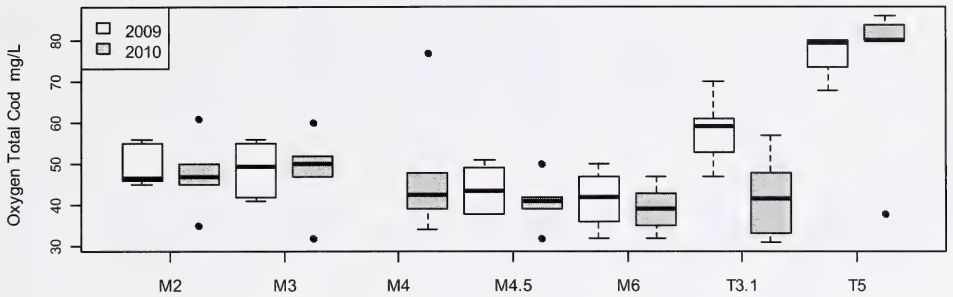

Selenium Dissolved ug/L
2009
2010
0
1
2
3
4
5
M2
M3
M4
M4.5
M6
T3.1
T5

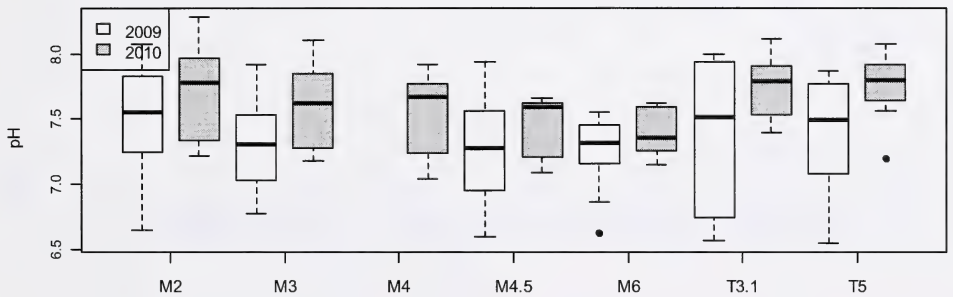

Nitrogen Dissolved Nitrite mg/L
2009
2010
0.00
0.02
0.04
0.06
M2
M3
M4
M4.5
M6
T3.1
T5

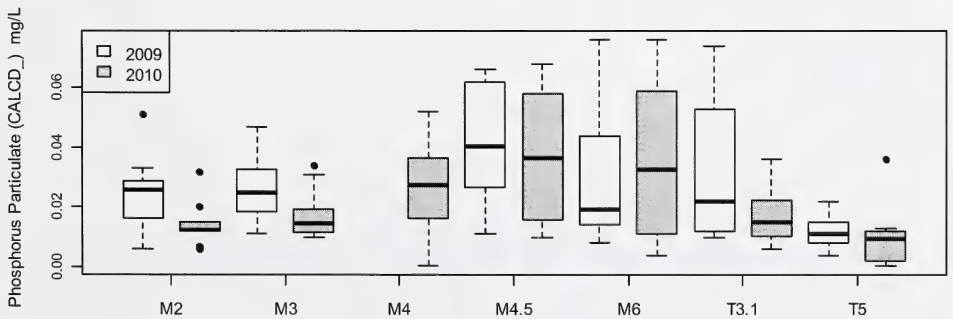

Nitrogen Dissolved NO3 & NO2 mg/L
2009
2010
0.0
0.5
1.0
1.5
2.0
2.5
M2
M3
M4
M4.5
M6
T3.1
T5

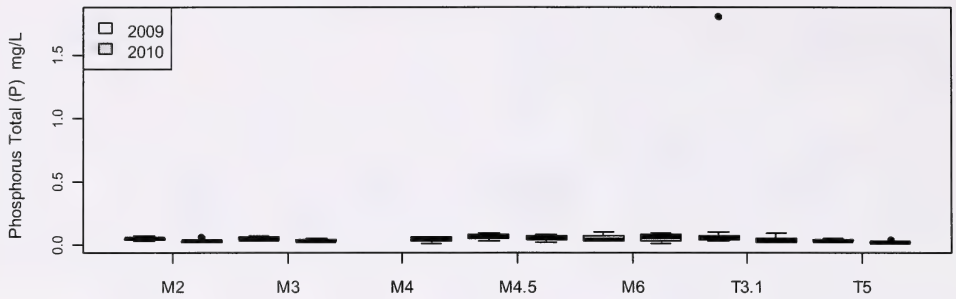

Nitrogen Total Kjeldahl (TKN) mg/L
2009
2010
0.6
0.8
1.0
1.2
1.4
M2
M3
M4
M4.5
M6
T3.1
T5

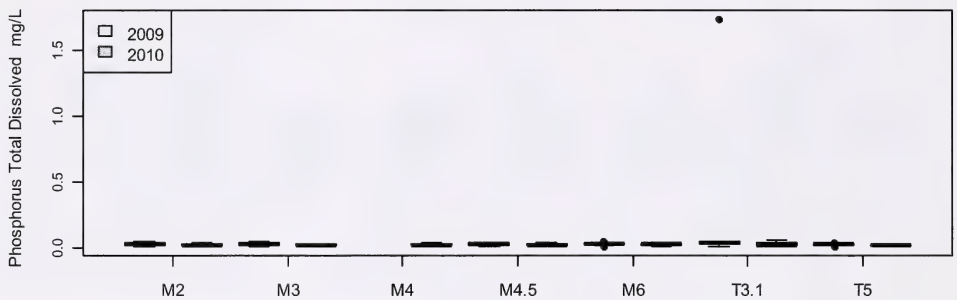

Oxygen Biochemical Demand mg/L
2009
2010
2
4
6
8
M2
M3
M4
M4.5
M6
T3.1
T5

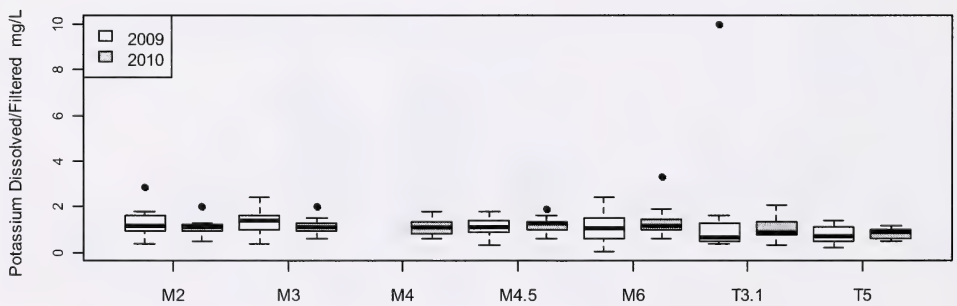

Oxygen Total Cod mg/L
2009
2010
30
40
50
60
70
80
M2
M3
M4
M4.5
M6
T3.1
T5

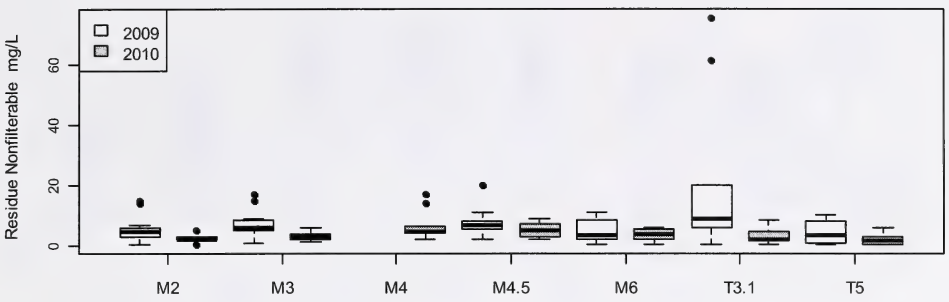

pH
2009
2010
6.5
7.0
7.5
8.0
M2
M3
M4
M4.5
M6
T3.1
T5

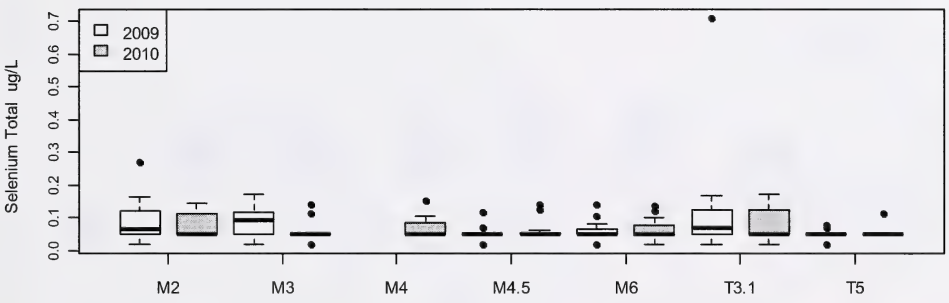

Phosphorus Particulate (CALCD_) mg/L
2009
2010
0.00
0.02
0.04
0.06
M2
M3
M4
M4.5
M6
T3.1
T5

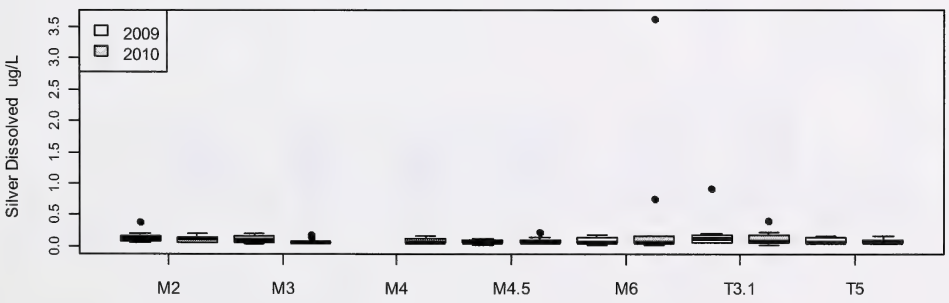

Phosphorus Total (P) mg/L
2009
2010
0.0
0.5
1.0
1.5
M2
M3
M4
M4.5
M6
T3.1
T5

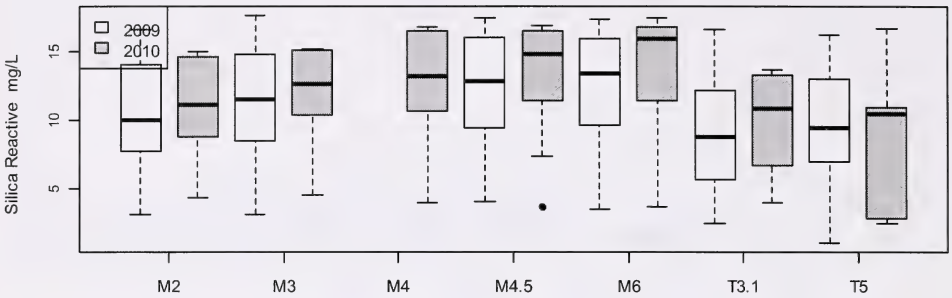

Phosphorus Total Dissolved mg/L
2009
2010
0.0
0.5
1.0
1.5
M2
M3
M4
M4.5
M6
T3.1
T5

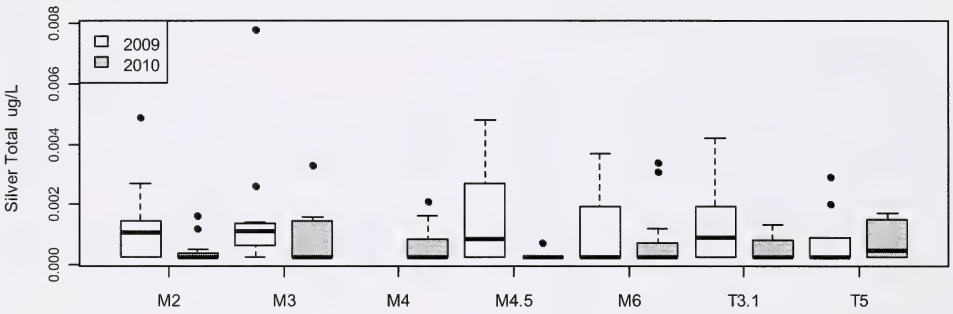

Potassium Dissolved/Filtered mg/L
2009
2010
0
2
4
6
8
10
M2
M3
M4
M4.5
M6
T3.1
T5

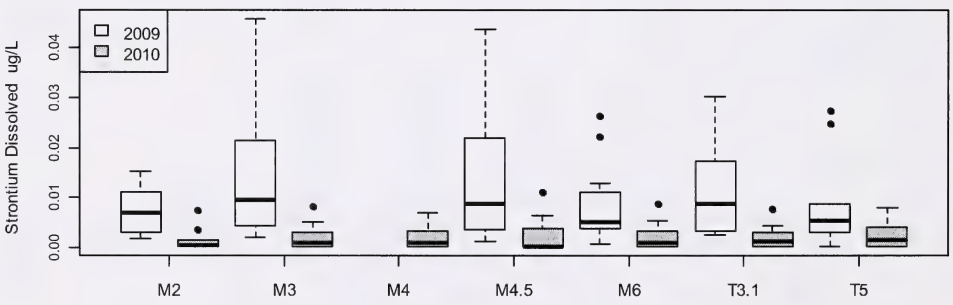

Residue Nonfilterable mg/L
2009
2010
0
20
40
60
M2
M3
M4
M4.5
M6
T3.1
T5

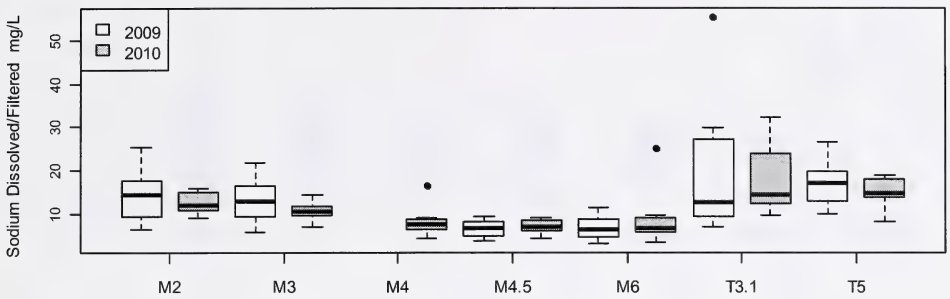

Selenium Total ug/L
2009
2010
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
M2
M3
M4
M4.5
M6
T3.1
T5

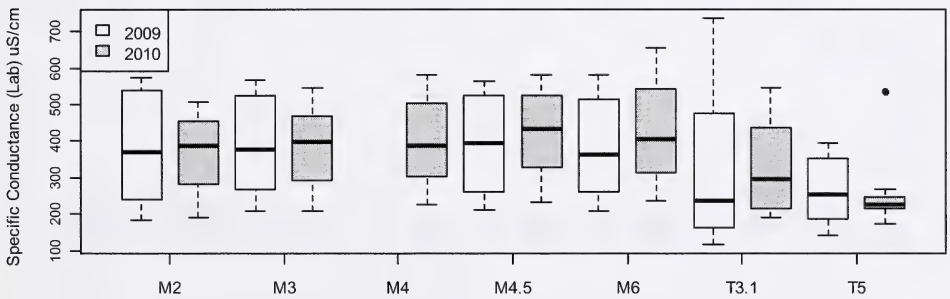

Silver Dissolved ug/L
2009
2010
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
M2
M3
M4
M4.5
M6
T3.1
T5

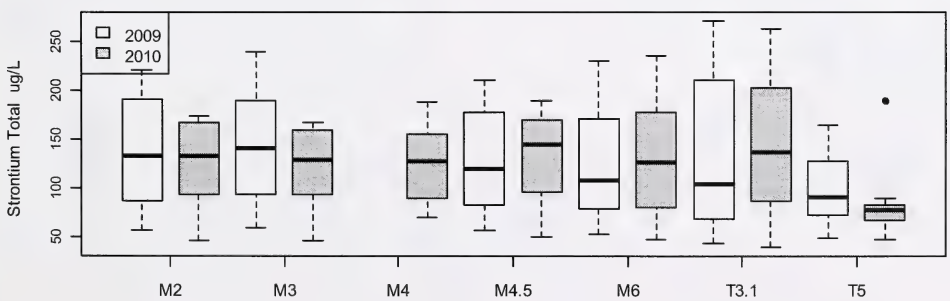

Silica Reactive mg/L
2009
2010
5
10
15
M2
M3
M4
M4.5
M6
T3.1
T5

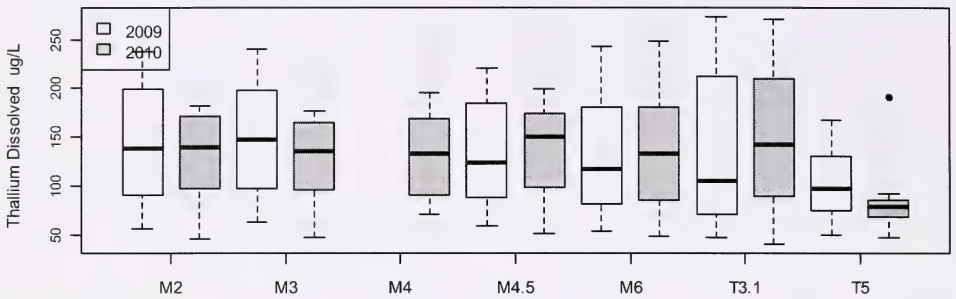

Silver Total ug/L
2009
2010
0.000
0.002
0.004
0.006
0.008
M2
M3
M4
M4.5
M6
T3.1
T5

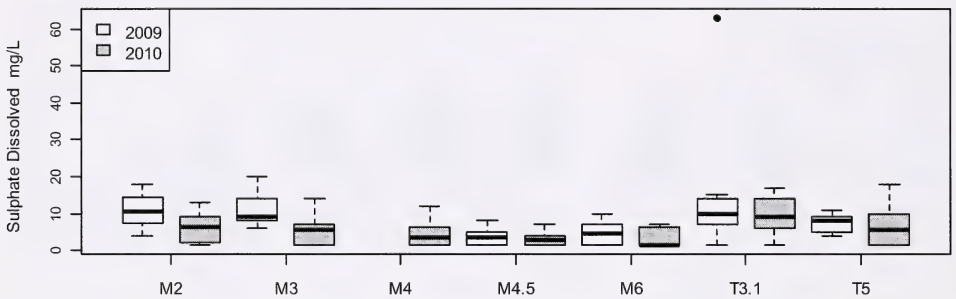

Strontium Dissolved ug/L
2009
2010
0.00
0.01
0.02
0.03
0.04
M2
M3
M4
M4.5
M6
T3.1
T5

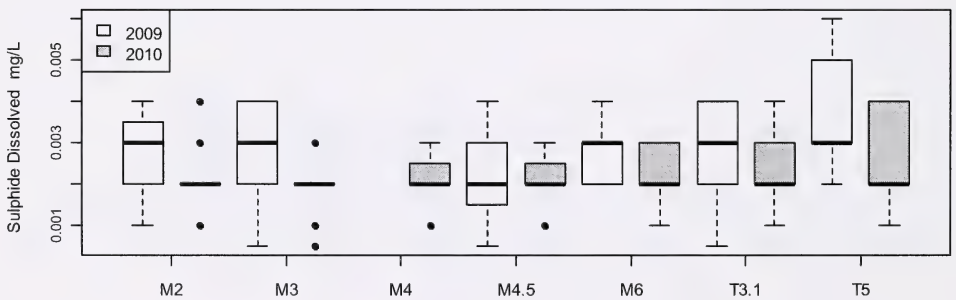

Sodium Dissolved/Filtered mg/L
2009
2010
10
20
30
40
50
M2
M3
M4
M4.5
M6
T3.1
T5

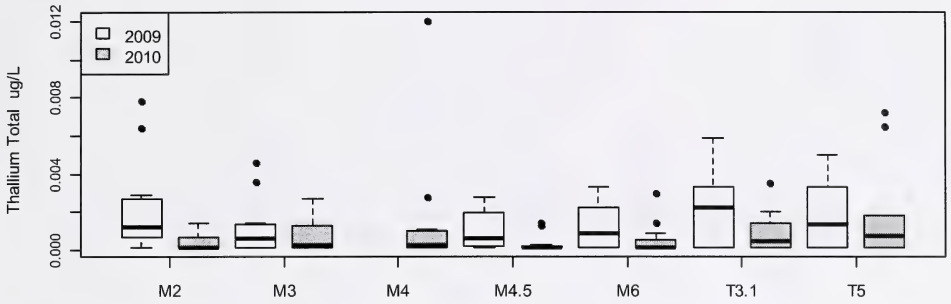

Specific Conductance (Lab) uS/cm
2009
2010
100
200
300
400
500
600
700
M2
M3
M4
M4.5
M6
T3.1
T5

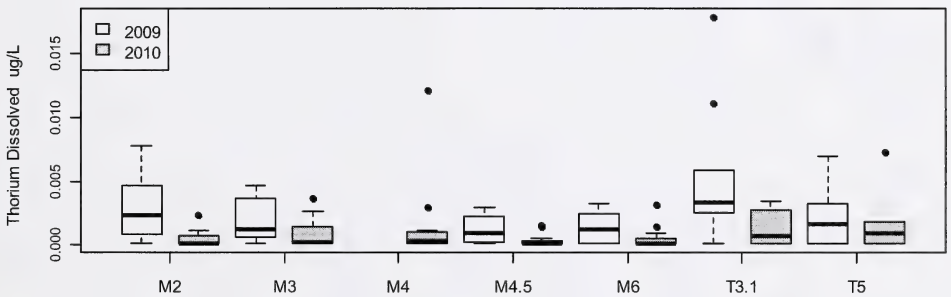

Strontium Total ug/L
2009
2010
50
100
150
200
250
M2
M3
M4
M4.5
M6
T3.1
T5

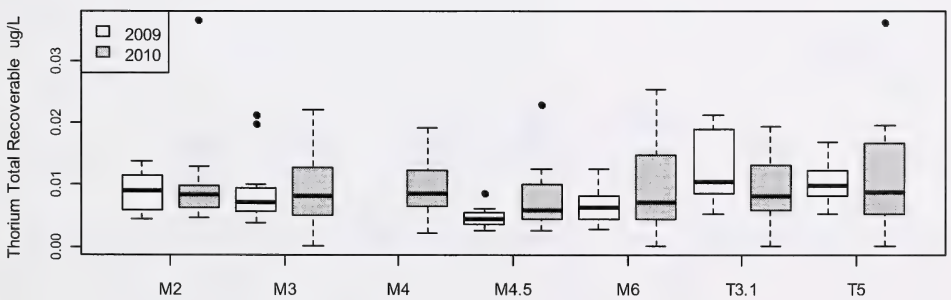

Thallium Dissolved ug/L
2009
2010
50
100
150
200
250
M2
M3
M4
M4.5
M6
T3.1
T5

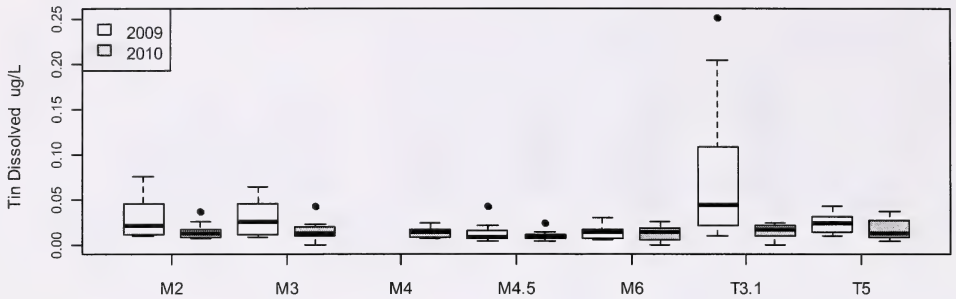

Sulphate Dissolved mg/L
2009
2010
0
10
20
30
40
50
60
M2
M3
M4
M4.5
M6
T3.1
T5

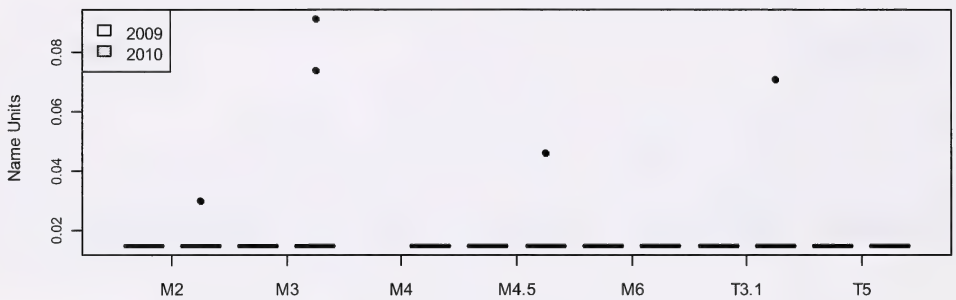

Sulphide Dissolved mg/L
2009
2010
0.001
0.003
0.005
M2
M3
M4
M4.5
M6
T3.1
T5

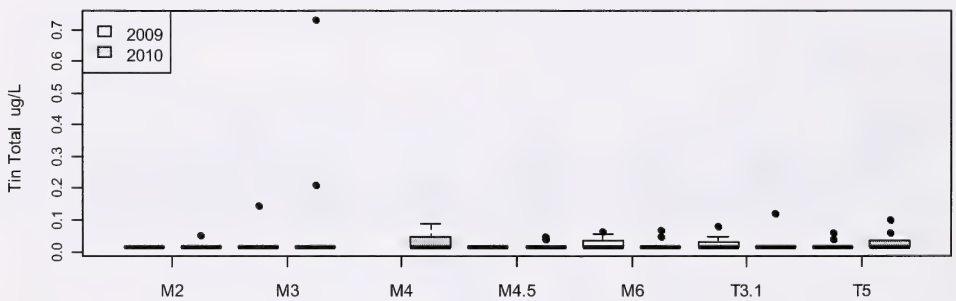

Thallium Total ug/L
2009
2010
0.000
0.004
0.008
0.012
M2
M3
M4
M4.5
M6
T3.1
T5

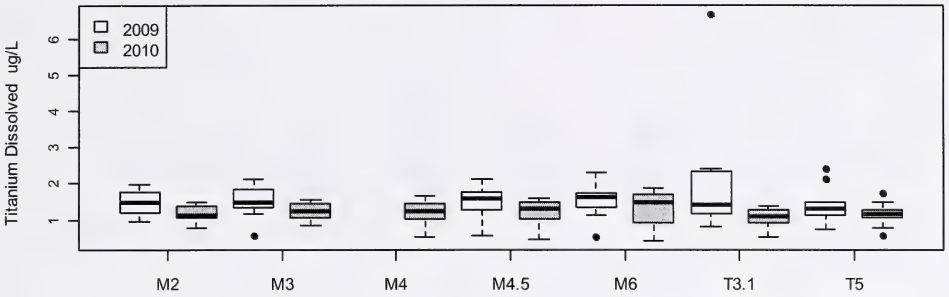

Thorium Dissolved ug/L
2009
2010
0.000
0.005
0.010
0.015
M2
M3
M4
M4.5
M6
T3.1
T5

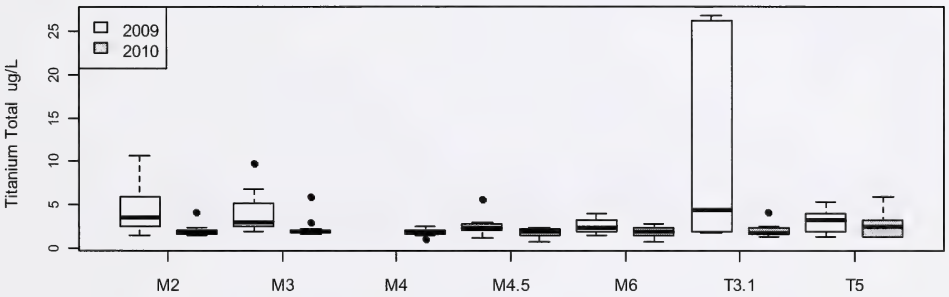

Thorium Total Recoverable ug/L
2009
2010
0.00
0.01
0.02
0.03
M2
M3
M4
M4.5
M6
T3.1
T5

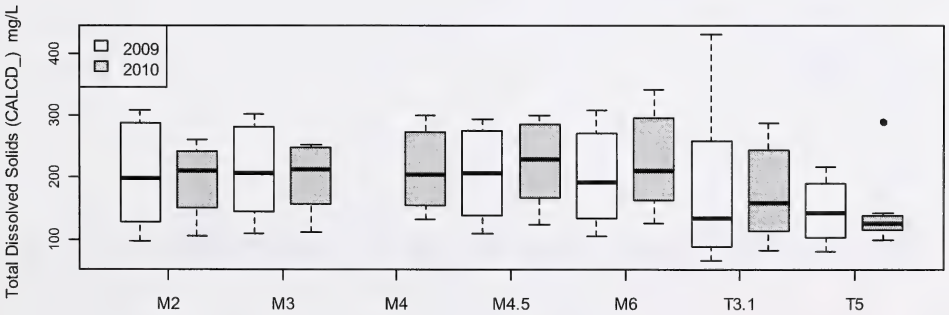

Tin Dissolved ug/L
0.00
0.05
0.10
0.15
0.20
0.25
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

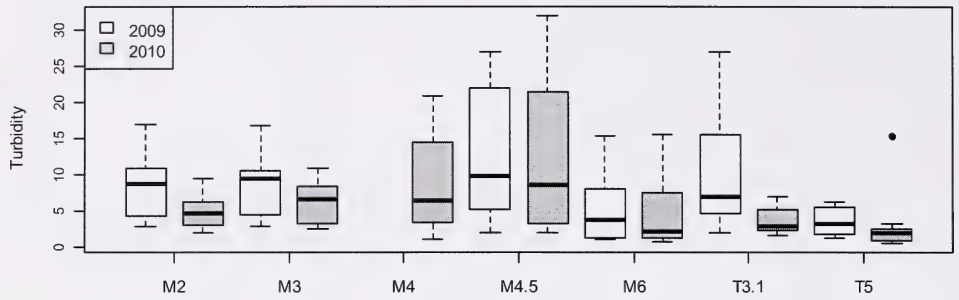

Name Units
0.02
0.04
0.06
0.08
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

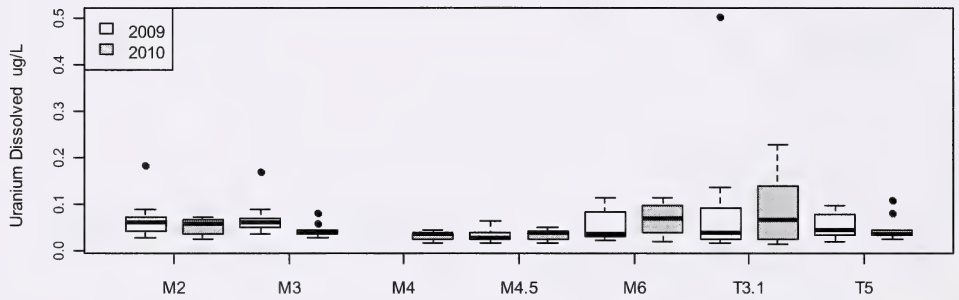

Tin Total ug/L
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2009
2010
M2
M3
M4
M4.5
M6
T3.1
T5

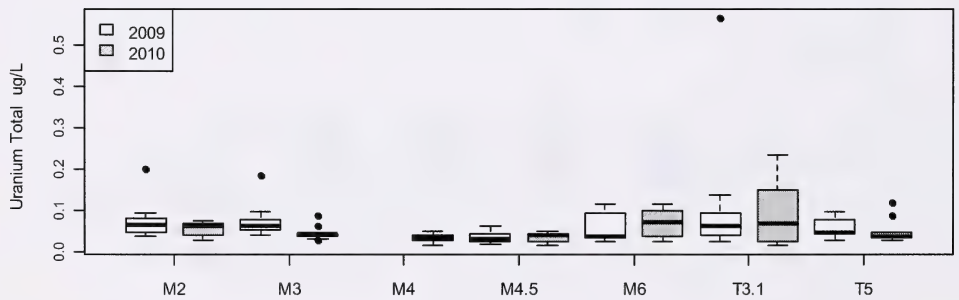

Titanium Dissolved ug/L
2009
2010
1
2
3
4
5
6
M2
M3
M4
M4.5
M6
T3.1
T5

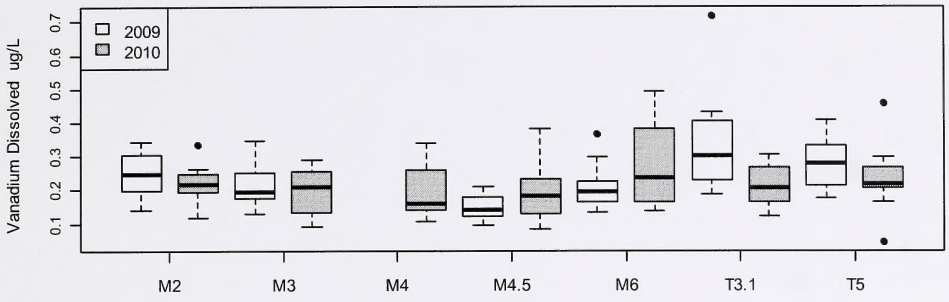

Titanium Total ug/L
2009
2010
0
5
10
15
20
25
M2
M3
M4
M4.5
M6
T3.1
T5

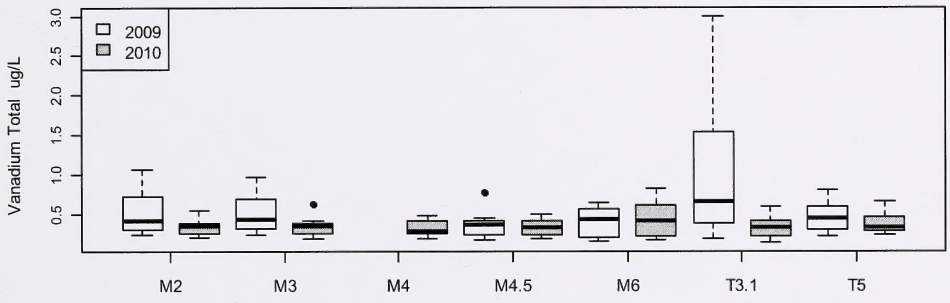

Total Dissolved Solids (CALCD_) mg/L
2009
2010
100
200
300
400
M2
M3
M4
M4.5
M6
T3.1
T5

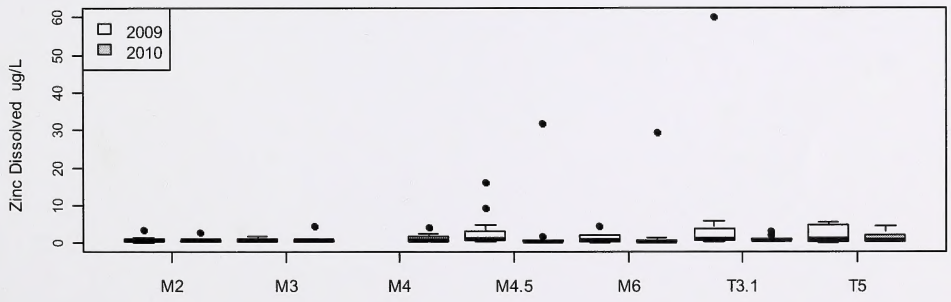

Turbidity
2009
2010
0
5
10
15
20
25
30
M2
M3
M4
M4.5
M6
T3.1
T5


Uranium Dissolved ug/L
2009
2010
0.0
0.1
0.2
0.3
0.4
0.5
M2
M3
M4
M4.5
M6
T3.1
T5


Uranium Total ug/L
2009
2010
0.0
0.1
0.2
0.3
0.4
0.5
M2
M3
M4
M4.5
M6
T3.1
T5


Vanadium Dissolved ug/L
2009
2010
0.1
0.2
0.3
0.4
0.5
0.6
0.7
M2
M3
M4
M4.5
M6
T3.1
T5


Vanadium Total ug/L
2009
2010
0.5
1.0
1.5
2.0
2.5
3.0
M2
M3
M4
M4.5
M6
T3.1
T5


Zinc Dissolved ug/L
2009
2010
0
10
20
30
40
50
60
M2
M3
M4
M4.5
M6
T3.1
T5

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